

# Black Spot Analysis

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Infrastructure impacts on the occurrence of black spots on  
the N1 highway in the Western Cape



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# **TERMS OF REFERENCE**

Professor Marianne Vanderschuren of the University of Cape Town initiated the research that has been undertaken in this thesis. The specific instructions given for the research were to:

- Perform a geographical analysis of the Western Cape accident database of the Provincial Government of the Western Cape (PGWC).
- Focus on infrastructure and geometrical variables which influence single vehicle overturning accidents.
- Analyse data from the South African National Roads Agency Limited (SANRAL) Cape Town database to determine potential hotspots and trends in the data.
- Draw conclusions and provide recommendations upon achieving the results.

The final thesis is to be submitted for evaluation before the end of August.

# Abstract

This thesis discusses the infrastructural, vehicular and environmental factors that contribute towards road accidents. The role of infrastructure in improving road safety is the primary focus of the research, as infrastructure influences the driving experience.

Road design and geometry are important for the consistency of highway performance. Road curvature, paved shoulders and the presence of an at grade intersection influence the drivers' perception of the highway.

The Laingsburg Beaufort West N1 highway has a high incidence of accidents, namely single vehicle accidents. For this reason, the road section has been classified as a hazardous location. These fatal accidents may be influenced by the infrastructural and geometrical factors of the highway. Western Cape geographical data was analysed for the period 2000 to 2007, to investigate the infrastructural and geometrical factors that influence the high accident rate. This was done through an ArcGis analysis, which gave insight into the properties of each of the fatal accidents. In order to get a level of confidence from the findings of the ArcGis analysis, a road safety audit was conducted. This was done through a general inspection of the N1 highway between Laingsburg and Beaufort West, which included driving through the road section at a constant speed, and completing a checklist of the operating elements of the highway. The road safety audit revealed that infrastructural problems (lack of guardrails, sign posts located close to highway) and geometrical factors (average paved shoulder width, single carriageway roads, and dangerous intersections) were present on the road. The Laingsburg Beaufort West analysis was the primary focus of the research.

Data for the years 2010 to 2013, which was updated, was obtained from SANRAL and investigated for accident types and potential hotspots. An ArcGis analysis was also performed on the data. Fatal accidents were analysed, to determine whether the Provincial Government of the Western Cape would meet their accident reduction goals of reducing accidents by 50% between the years 2009 and 2014. A high incidence of fatal pedestrian accidents was observed in the Khayelitsha area.

Recommendations include the relocation of poles and signs, increasing the paved shoulder width, installation of guardrails along the entire highway, as well as provision of pedestrian bridges and walkways in the Khayelitsha area.

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# Technical Terms, Acronyms and Symbols

Technical Terms	
Pedestrian	A person who travels by foot and not through a vehicle
iPas	Database used by the PGWC to collect and store road accident data
Traffic calming	Management measures designed to lower traffic speeds or redirect traffic to alternative routes to avoid congestion, reduce accidents and injuries and prevent excess pollution.
Black spots	A fatal accident hazardous location.
Hot spots	A fatal accident hazardous location. Same as black spot.
ArcGIS	A suite consisting of a group of geographic information system (GIS) software products. It includes ArcReader, ArcView, ArcEditor and ArcMap.
Jaywalk	To walk in or cross the road without regard for approaching traffic
Shapefile	Files used in ArcGIS to store geographical data
Acronyms	
PGWC	Provincial Government of the Western Cape
RTMC	Road Traffic Management Corporation
FID	Feature Identification Class on ArcGIS
SANRAL	South African National Road Agency Limited

# **1. Introduction**

## **1.1. Background to study**

This research focuses mainly on the role that infrastructural, vehicular, and human factors have on the occurrence of road accidents. The main area of focus will be the N1 highway in the Western Cape, as there is a high incidence of single-vehicle accidents.

Developed countries generally have less fatal accidents than developing countries due to more advanced infrastructure, and stronger legislation and road safety campaigns (Berhanu, 2003).

South Africa records a high rate of road fatalities when compared globally, with an estimated 31.79 fatalities per 100 000 inhabitants (RTMC, 2011). The loss of life not only poses a problem to the South African economy, but also to the victims' families', as the victims are usually the primary breadwinners, hence pushing families further down the poverty line (Vanderschuren and Jobanputra, 2011).

## **1.2. Problem statement**

This research aims to bring to attention the phenomenon of increased road accidents in developing countries. The problem of traffic accidents is a major concern in developing countries, because of the seriousness to develop feasible countermeasures and the limited resources available for reducing this ever-growing challenge (Berhanu, 2003). Developed countries have designed and implemented different strategies to reduce the scale and severity of this problem through education, enforcement and engineering (Berhanu, 2003).

It has also been shown that an improvement of infrastructure can lead to an increase in accidents (Noland, 2003). This may be due to motorists believing that better equipped roads are inherently safer, thereby leading motorists to take more risks, thus increasing the likelihood of accidents (Noland, 2003).

However, the inadequate provision of road infrastructure can lead to an even greater increase in road accidents. This is mostly true for developing African countries, such as Ethiopia, which have several infrastructure problems which contribute to 65% of the road accidents. According to Berhanu (2003), 'Traffic controls, signs and road markings are not properly maintained and pedestrian facilities are not in place'.

This thesis, thus, aims to identify the road infrastructure measures that are important in ensuring the increased safety of motorists on roads, and thereby a decrease in road accidents.

### **1.3. Description of the main problems to be investigated**

The main problems to be investigated in the research therefore include:

#### **1.3.1. What is the role of infrastructure in improving road safety?**

The provision of the proper infrastructure on national roads can greatly affect the incidence of road accidents. This can include subtle measures such as the provision of proper warning posts at various sections of road that have a higher probability of road accidents. Other important infrastructure intervention methods may include clear barrier lines on the road so that motorists know which manoeuvres are acceptable on the road; the provision of guardrails to prevent cars from veering off the road unintentionally, and the maintenance of roads to prevent potholes from occurring which can lead to severe accidents and vehicle damage.

This research assumes that with the improvement of infrastructure, the level of accident occurrence will decrease significantly. This infrastructure can be in the form of traffic controls, road signs, road markings and traffic calming measures to increase pedestrian safety. Other interventions that can be implemented to improve driver and pedestrian safety are increasing the widths of the sidewalks (Berhanu, 2003) to give pedestrians more room for movement.

#### **1.3.2. What is the importance of road geometry in reducing road accidents on highways?**

‘Design consistency is the conformance of geometry of a highway with driver expectancy, and its importance and significant contribution is justified by understanding the interaction between driver-vehicle-highway’ (Sayed et al, 2004). The consistency of geometric design is becoming important in highway design. Being able to identify and remedy an inconsistency on a highway greatly improves the safety performance.

#### **1.3.3. Is there a higher incidence of single vehicle overturning accidents than other type of road accidents along the N1 between Laingsburg and Beaufort West?**

Some attention will be drawn to single-vehicle accidents occurring mainly on the N1 highway between Laingsburg and Beaufort West, with emphasis on overturning accidents.

Data for the years 2000 to 2007 showed that there seems to be an upsurge in these accident types, leading to the assumption that highway infrastructure is important to ensure that there is a decrease in accident frequency.

Due to the accidents being fatal, it is also important to determine whether this N1 section can be classified as a hazardous location.

#### **1.3.4. Does the available geographical data give insight into the variables contributing to single vehicle overturning accidents?**

Provincial authorities such as the Provincial Government of the Western Cape and South African National Roads Agency Limited have made available geographical data for analysis. The data will assist in determining the variables that contribute mostly to fatal accidents along the N1 in the Western Cape. The data provided by the PGWC included accident data for the Western Cape municipalities, excluding the City of Cape Town. The City of Cape Town data was provided by SANRAL. Due to the fact that the N1 highway route traverses along the City of Cape Town municipality, this data was also investigated for fatal accidents.

#### **1.3.5. Has the PGWC achieved its accident reduction goals?**

The Provincial Government of the Western Cape aimed to achieve a 50% accident reduction rate between the years 2009 and 2014 through the Safely Home Campaign. The N1 highway passes through the City of Cape Town, therefore, fatal accident occurrence was also to be analysed within the municipality. The accident data was provided by SANRAL, as it is the governing body of all highways in the country. The SANRAL data analysis is done as a secondary investigation for the research.

### **1.4. Goals and Objectives**

The main goal of the research is to determine whether the high incidence of single vehicle overturning accidents along the N1 between Laingsburg and Beaufort West is infrastructure related. The specific objectives of the study include:

- i. To identify infrastructure and geometrical problems that contribute to single vehicle overturning accidents.
- ii. To ascertain whether single vehicle overturning accidents occur more than other types of accidents in the study area.

- iii. To determine whether the N1 between Laingsburg and Beaufort West can be classified as a hazardous location.
- iv. To analyse the available geographical data of the Western Cape to determine factors that contribute to fatal single vehicle overturning accidents
- v. To determine whether the Provincial Government of the Western Cape has achieved its accident reduction goals.

## **1.5. Methodology summary**

The methodology consists of different stages for the data collection, collation and analysis procedure. Raw data for the Western Cape was obtained from the Provincial Government of the Western Cape, for the years 2000 to 2007. The data was initially analysed using ArcGIS, to locate the hazardous locations along the N1 between Laingsburg and Beaufort West. After these locations were selected, the properties of each of the fatal accident locations were analysed for the infrastructure problems which influence the frequency of fatal single vehicle overturning accident occurrence, hence making them hazardous locations. This analysis was performed using ArcGIS.

The properties of the hazardous locations were then extracted from ArcGIS and a numerical analysis was performed on Microsoft Excel, to determine if any trends in the data which relate to infrastructure problems existed.

A Road Safety Audit was also performed on the 21<sup>st</sup> of September 2013, to observe the infrastructure that currently exists on the N1 highway, which may influence single vehicle rollover accidents.

Data from SANRAL, for the years 2010 to 2013 was also analysed on Microsoft Excel to determine any hazardous locations within the City of Cape Town municipality. This accident data was the only updated information available for the City of Cape Town, as the PGWC data did not provide information on the City of Cape Town Metropolitan Municipality.

## **1.6. Scopes and limitations**

The research covers data provided for the Western Cape Province only. The analysis of the data included a geographical analysis, as well as a Road Audit of the existing conditions of the highway.

Video data collected during the road audit was for one designated day. A night-time inspection was not conducted. This daytime video was not enough to enable the researcher to fully capture changes that occur during the year, which may govern the occurrence of accidents.

## **1.7. Chapter Summary**

The research topic is the analysis of infrastructure problems which influence single vehicle overturning accidents in the Western Cape. Infrastructure problems contribute to the rising number of road fatalities in the country.

Road infrastructure and road geometry have the potential of reducing road accidents, if provided correctly and adequately. The type of accidents that occur predominantly on the N1 are single vehicle overturning accidents, which are affected by road infrastructure. The purpose of the research is therefore to highlight the importance of road safety research, as well as the risk factors associated with single vehicle accidents.

The contents of the Thesis document include a literature review, methodology adopted in the research, research findings. Conclusions and recommendations are discussed in the last chapters of the document.

## **2. Literature Review**

### **2.1 Introduction**

This chapter reviews the already existing literature regarding road accidents and factors influencing road accidents. Schuler (1940) suggests that the road geometry and road environment are important factors which influence road accidents. Petridou et al. (1997) further suggest that individuals from left side driving countries become more prone to road accidents when the driving environment changes to a right-side driving environment. Human factors which increase the likelihood of road accidents were investigated by Vanlaar (2006). These included cases such as drunken driving. Vehicle factors such as defective steering were also investigated by Hoekstra and Wegman (2011) Methods used by African countries to increase the number of passenger seats also influenced passenger safety when accidents occurred.

Chen and Chen (2010) further investigated the risk of single vehicle overturning accidents increases, on straight and curved roads during inclement weather conditions.

Infrastructure impacts and improvements were reviewed by Noland (2003), with Berhanu (2004) investigating the road infrastructure problems faced by African countries. Traffic calming measures are investigated by Vanderschuren and Jobanputra (2009).

Collection of road accident data and problems encountered when trying to keep an updated database are reviewed by Thwala (2012).

Two case studies are presented at the end of the chapter. The first case study investigates hazardous locations in Cameroon, West Africa. The second case study, carried out by Vanderschuren and Jobanputra (2011) on the Western Cape, gives information about hazardous locations.

### **2.2 The cause of road accidents**

Various reasons exist for the prevalence of road accidents in the present day. The most dangerous actions considered important by more than 80% of respondents of a study conducted in Turkey were 'insufficient knowledge of traffic laws; dangerous parking; drug or alcohol consumption and the three causes perceived to be least important were: bad luck, absence of pavements and sanctions being too lenient'. (Vanlaar, 2006)

The driving environment and driving experience can be a contributing factor in the occurrence of accidents. A study conducted by Petridou et al. (1997) showed that foreign nationals from left-side driving countries are at an increased risk of being involved in accidents than people originally from Greece, more so when driving a rented vehicle than a privately owned vehicle. This is plausible, due to the major change in driving environment for the foreign individuals (Petridou et al., 1997).

Poor road conditions were also believed to be the leading cause of accidents in 1938 by J.W. Vickery, a highway safety engineer (Schuler, 1940). These road conditions consisted of 'poor visibility because of grade or alignment, slippery pavement, loose gravel, bumpy surface, narrow roadways, at a bridge or underpass, soft shoulders, misplaced signs or signals, obstructions caused by rocks or slides or trees or previous accidents or construction in progress' (Schuler, 1940). When a road faces such problems, it can be fixed through simple physical changes and that will result in the decrease in the incidence of accidents.

### **2.2.1 Human factors**

It is a well-documented fact that **drinking and driving** increases the likelihood of being involved in a car accident. It is also reported that persons who are under the influence of alcohol and get involved in accidents are more likely to suffer severe injuries than sober individuals (Vanlaar, 2006). It is for this reason that road safety experts acknowledge the fact that drinking and driving is very risky and increases the potential of a road accident occurring. Road users are unaware of the fact that once an accident occurs, the severity of the accident will vary according to the level of intoxication of the individuals involved. (Vanlaar 2006)

Another interesting factor is that visiting foreign nationals who are in a vacationing mood are more likely to be intoxicated when involved in accidents (Petridou et al., 1997). Their countries of origin usually have strict laws against driving under the influence of alcohol however when on vacation, they are more likely to break the law of other countries.

### **2.2.2 Vehicle factors**

Vehicle factors may also contribute to the occurrence and severity of road accidents. According to a study conducted by Hoeskstra and Wegman (2011), defective steering was among the causes of accidents, although it had a low prevalence but a high risk. Of the total respondents in the study, 3.3% believed that defective steering is never the cause of an accident and 9.5% believed that it is always a cause (Hoeskstra and Wegman, 2011).

Afukaar (2003) also noted that in some African countries, such as Ghana, the use heavy of metal works to increase the number of passenger seats for open trucks have proven to be a major safety risk in case of a road accident.

Although not prevalent, vehicle factors can thus be said to have a contribution towards the incidence of road accidents. Motorists and traffic officials are to make sure that road worthy vehicles are on the road, and vehicles that are not road worthy should either be issued hefty fines, or impounded.

### **2.2.3 Legislation**

Afukaar (2003) emphasizes that ‘for many years, police have played a prominent role in improving road safety’. Developing countries tend to achieve their road safety goals through measures, such as the imposition of speed limits, police enforcement of traffic laws and traffic calming measures in general (Afukaar, 2003). Therefore, police presence at known accident hot spots can be effective at making motorists reduce risky behaviour on the road.

Other variables worth considering in road accident prevention are whether there are any laws regarding seatbelt and helmet usage. This refers to whether primary laws, laws allowing traffic officials to fine any individuals for not wearing a seatbelt. Primary laws were found to reduce fatalities and injuries (Noland, 2003).

European countries, such as Spain have introduced a Points demerit system according to Law 17/2005. This measure has been in effect since middle of 2006 and penalises reckless driving by motorists (Albalate et al, 2013).

Legislation can, however, be important in reducing road accidents. Methods to enforce seatbelt usage, decrease the incidence of drunk driving and lowering speed limits are effective accident preventative measures. Lowering the Blood Alcohol Limit, as was done in Spain, to 0.5mg/ml from 0.8mg/ml (Albalate et al, 2013) has also proven to be effective.

## **2.3 Road Environment**

The road environment is an important part of the driving task. An under-stimulating driving environment contributes significantly to fatigue and monotony. Simulator studies are usually the preferred method of studying the effect of the road environment to the driving task

A total of fifty six male participants were selected in a simulator study conducted in Montreal, Canada. The male subjects were exposed to different driving environments which included; a

bare road environment, the second scenery (road A) presented pairs of pine trees, one tree on each side of the road, which passed by the driver at the rate of one pair per second at a speed of 130 km/h (Thiffault et al., 2002). The third scenery (road B) was intended to be monotonous but without the repetitive environment of road A. Road B also included visual stimuli representing elements that are likely to be seen in a rural setting. It was bordered by infrequent random trees, houses and farms. There were occasional pedestrians on the roadside and in the fields (Thiffault et al., 2002).

Subjects had a marked tendency to deviate to the middle of the road due to the presence of pedestrians on the roadside and narrow bridges which they had to cross. This further suggests the driver's alertness in the presence of a variable roadside environment (Thiffault et al., 2002).

The simulator study further indicated that fatigue is likely to manifest itself quite rapidly under driving conditions where the driver receives little sensory stimulation (Thiffault et al., 2002).

Another simulator study was conducted in the Netherlands to study the effect of lighting and a variable driving environment. The study carried out in Netherlands aimed to determine whether different single-vehicle accident rates on two different roads is due to the drivers' different appreciation of these roads. The basic assumption for the research was that the experience of the road environment is an important factor in driving behaviour (Frank et al., 1994). It was expected that the more understimulating road would have more single vehicle accidents

'Highway hypnosis' may be a direct result of under-stimulation from the road and traffic environment, hence, leading the driver to ignore relevant information that the driving environment gives.

The two roads, Drente and Polder Road, were compared under two conditions of ambient lighting and traffic.

Figure 2.1 shows Polder Road. It is, absolutely, flat, the horizon is a horizontal line and the road has very few curves, which can be seen for kilometres ahead. This road type has vegetation mainly on one side, consisting of low trees and bushes of equal height (Frank et al. 1994)



**Figure 2.1: Polder Road**

*Source: Frank et al, 1994*

The other road, Drente Road,( see Figure 2.2) had a road environment that ‘had bushes in groups, a small forest with high fir-trees, open spaces and a horizon that was not a horizontal line but consisted of the contours of bushes and forests’(Frank et al. 1994). More green vegetation was present on Drente Road as compared to Polder Road, which had vegetation, which was not as variable as Drente Road. The road also consisted of a certain number of modest slopes curves were similar to Polder Road.



Figure 2.2: Drente Road

Source: Frank et al, 1994

The participants were to assess the virtual environment using the following conditions:

*Changeable, Demanding, Increases alertness, Irritating, Lower Attention, Monotonous, Threatening, Relaxing, Lowers concentration, Gives a Good View, Dangerous, Enjoyable, Spacious, Peaceful, Boring, Increases wakefulness.*

As expected, the participants tended to rate Drente Road higher than Polder Road, which proves that Drente Road is more appreciated and provides better stimulation to the driving experience. It would therefore be expected that Drente Road would have less single vehicle accidents, in comparison with Polder Road, due to the stimulating driving environment.

It can therefore be concluded that the road environment is an important aspect of reducing accident frequency of highways. Soft engineering measures are to be considered by highway designers and urban planners. These would include lighting conditions at certain locations of the highway, as well as variable vegetation throughout the highway section. Depending on the location of the highway, the presence of pedestrians is shown as being important to induce driver alertness during the driving task.

## 2.4 Road Geometry and Design

Road geometry is an important aspect of highway design. It is a well-documented fact that an improvement in highway design would result in an improvement in accident rates. Engineers and transportation planners are constantly evaluating means to improve fatality rates. Part of the evaluation process entails being able to predict accident rates and accident locations. Karlaftis et al., (2002) aimed to employ a method known as Hierarchical Tree Based Regression (HBTR) to predict accident rates, using geometrical factors as dependent variables.

Results of the HBTR analysis showed that the existence of a median is an important factor for low flows while when it comes to higher flows, the existence of access control seems to be the more important factor safety wise Karlaftis et al, (2002).

For the rural two-lane case, lane width (LW) is the variable with the higher importance after Annual Average Daily Traffic (AADT). It is obvious that the proximity of the opposing traffic streams renders the width of the lane an important factor for safety. The next important variables; Serviceability Index (SI), Friction (FR) and pavement type, are related to the road pavement conditions. However, when it comes to multilane rural roads the variables with the higher importance after AADT are the existence of a median and of access control. These two factors, however, resulted in increased speeds on multilane rural roads. This fact renders the above two factors more important than lane width. The existence of a median, however, becomes more important in low flow conditions.

Although the importance of isolated variables differs for the two roadway types it is obvious that ‘geometric design’ captured through lane width and access control and ‘pavement condition’ captured through friction, serviceability index and pavement type are, as expected, the two most important factors affecting accident rates.

Paved shoulders are a structural element of the total pavement, providing lateral support to the traffic lanes, and allowing construction-related edge effects to be located away from the trafficked section of the pavement. It allows drainage of water away from the trafficked section of the pavement, and increases the effective width of the traffic lanes and therefore increases the lateral clearances between opposing vehicles on an undivided road. It can also be said that road pavements are an important *geometrical and infrastructural* element which assist in the prevention of **single-vehicle accidents**. Ogden (1997) investigated the effect of paved shoulders on accidents on rural highways

The most common type of accident was involved a **single vehicle leaving** the road and hitting a fixed object. The shoulder provided a recovery area for errant vehicles, i.e. allowing space for an out-of control vehicle to be brought under control. It also, in some instances, provided an avoidance space, giving a driver room to avoid colliding with another vehicle that has intruded into the traffic lane. The shoulder may be used to provide a space for very slow vehicles to allow faster vehicles to pass. Values of a statistical analysis performed by Ogden (1997) suggested that there appeared to be significant safety benefits resulting from paving the shoulders on two-lane rural roads. The benefit mainly arose from reductions in single-vehicle run-off-the road accidents (which may be due to reducing or eliminating loss of control when a vehicle strays onto an unpaved shoulder, and also increased recovery space) and multi-vehicle opposite-direction accidents (which may be due to increased recovery space, together with increased avoidance space).

In cases where the geometrical design of the road may be considered hazardous and unalterable, it is common to place warning signs and posted speeds. Sehmeida (2013) investigated the effect of highway geometry on posted speed in multi-lane highways in Egypt Cairo. The road geometric data was collected directly from a site investigation which included lane width, right shoulder width, number of lanes in one direction, median width, pavement width, and existence of side access along the section (Sehmeida, 2013). Results of a linear regression carried out revealed that for side accesses, the operating speed decreased with the existence of side access. The drivers become cautious when they observe side access signs ahead; consequently, they decrease their speeds.

Conversely, a regression analysis indicated that operating speed increases when the road shoulder width increased. This result seems reasonable as drivers would tend to take more risks when overtaking in areas where a road shoulder existed. However, Ogden (1997), observed safety benefits from increasing road shoulder width. The road shoulder provides enough space for illegal overtaking opportunities for drivers. Sehmeida (2013) found that the most influential geometrical factors on highway operating speed in Egypt are pavement width, median width and side accesses. An increase in pavement width (6.8m to 7.1m) resulted in an increase in operating speed of 40km/h. An increase in median width (2.2m to 2.8m) also resulted in an increase in operating speed of 27km/hour. The only variable that was found to have a decreasing influence on highway speed was the existence of side accesses, as motorists are wary of vehicles approaching from these accesses. This finding is further discussed by Karlaftis et al., (2002), who noted that the existence of accesses was

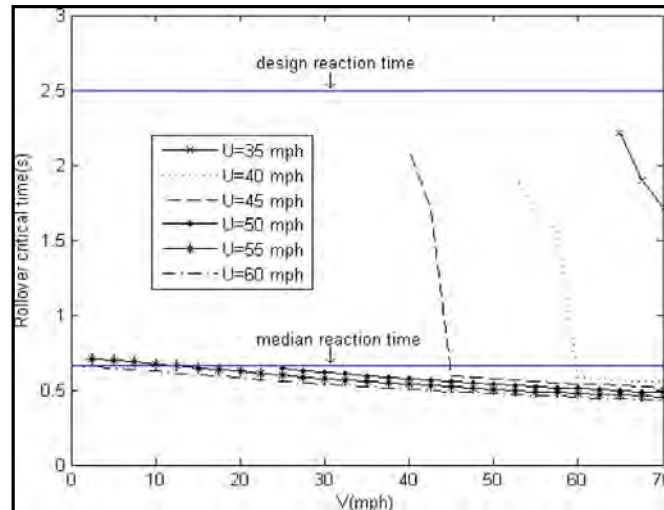
important in multi-lane rural roads, although it resulted in increased speeds. Increased operating speeds are not the desired effects by engineers, as they may result in severe road accidents.

Cruzado and Donnell (2010) argued that speed differentials are associated with transition zones. This can be in the form of a change in built up area, to the presence of an at grade intersection (side accesses). In his study, speed reductions were observed when vehicles entered a curve, when the degree of curvature increased and also when the vertical grade increased (Cruzado and Donnell, 2010). Fwa et al, (2002) also suggested that a speed differential is caused by speed reductions of heavy vehicles during an upslope climb (change in vertical grade). This limits the passing efficiency of the vehicle.

Chen and Chen (2010) investigated the effect of road geometry and its effect on **single vehicle overturning accident**. This study was conducted using a simulation-based vehicle assessment model, which aimed to analyse heavy motor vehicles.

Vehicles such as trucks, emergency vehicles and sport utility vehicles (SUV's) are often at an increased risk of experiencing a single vehicle accident when driving conditions are harsh. This may be due to inclement weather or complicated topographical conditions (Chen and Chen, 2010). The vulnerability of the above mentioned vehicles is also increased due to their mass, as roll-over and sideslip accidents are hard to prevent due to the momentum of the vehicles.

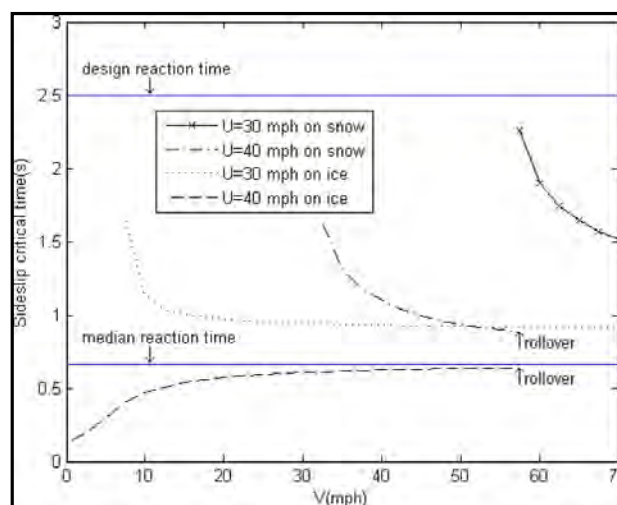
Large vehicles such as trucks and SUV's are specifically prone to single-vehicle accidents (roll-over or sideslip) under hazardous driving environments on rural roads (such as highways). When a truck travels on a straight road with a dry road surface, roll-over accidents tend to occur first. This can be attributed to wind effects on the vehicle. The relationship between wind speed  $U$  and Critical Sustained Time (CST) of rollover is shown in Figure 2.3 (Chen and Chen, 2010).



**Figure 2.3: Rollover accidents with different wind speeds**

*Source: Chen and Chen (2010)*

When a truck is driven on a straight road with an ice or snow surface, sideslip accidents tend to occur first. Figure 2.4 illustrates the relationship between driving speed and the wind speed. When the wind speed exceeds 65 km/hour, sideslip accidents start to occur.

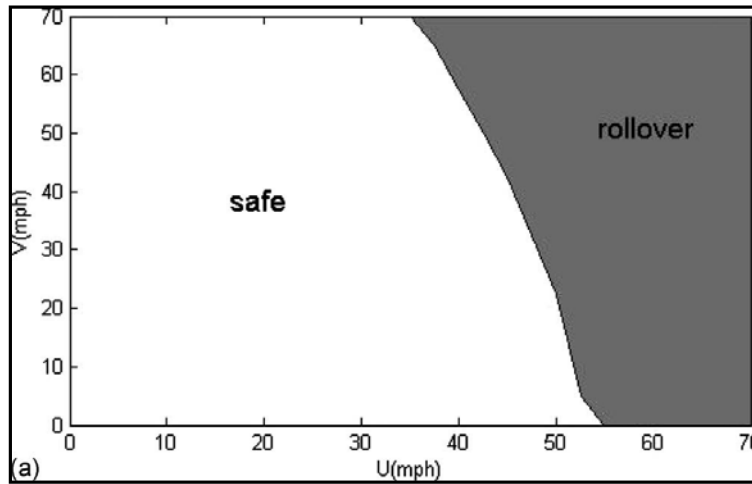


**Figure 2.4: Sideslip accidents with different wind speeds**

*Source: Chen and Chen (2010)*

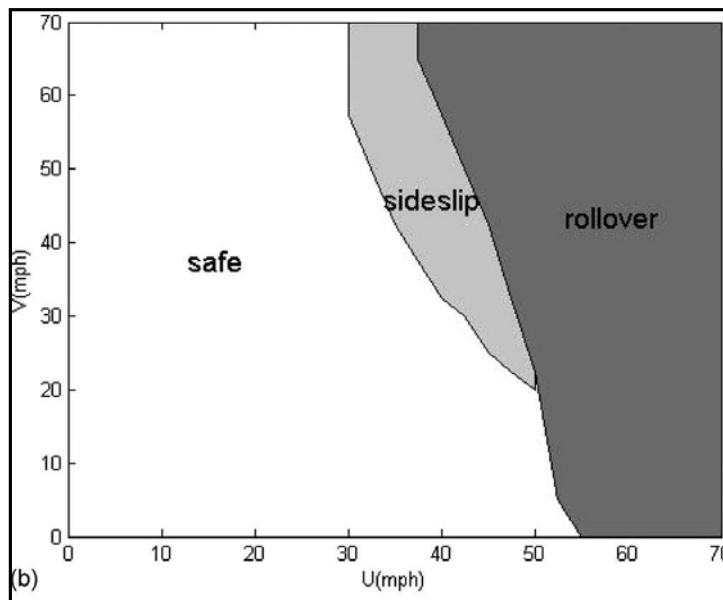
When the wind speed increases, the Critical Driving Speed (CDS) will decrease. Figure 2.5 suggests that rollover accidents will occur when the heavy vehicle is on a dry road. The risk of rollover tends to increase when the wind speed exceeds 56 km/hour. Even when the truck is not in motion, with a wind speed of 89 km/hour, the risk of rollover still exists. Figure 2.6 shows the accident risks when the vehicle is on a snow-covered road. Sideslip accidents are

more likely to occur when the driving speed reaches 32km/hour as shown in the figure. Rollover accidents occur when the wind speed reaches 89 km/hour. Figure 2.7 shows the relationship between vehicle and wind speed on an icy road. Sideslip accidents can occur when the wind speed is below 32km/hour and the vehicle speed is 40km/hour on icy roads.



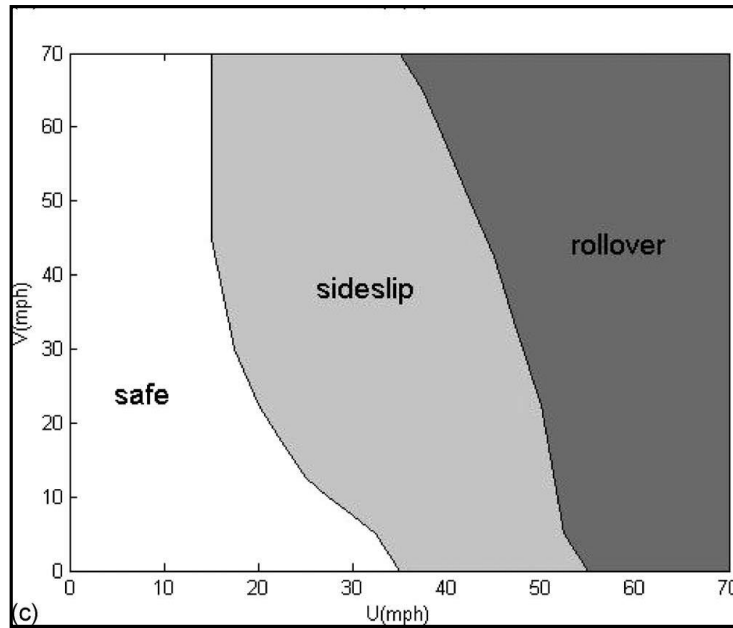
**Figure 2.5: Rollover accidents on a dry road**

*Source: Chen and Chen (2010)*



**Figure 2.6: Accidents on a snow covered road at different wind speeds**

*Source: Chen and Chen, (2010)*

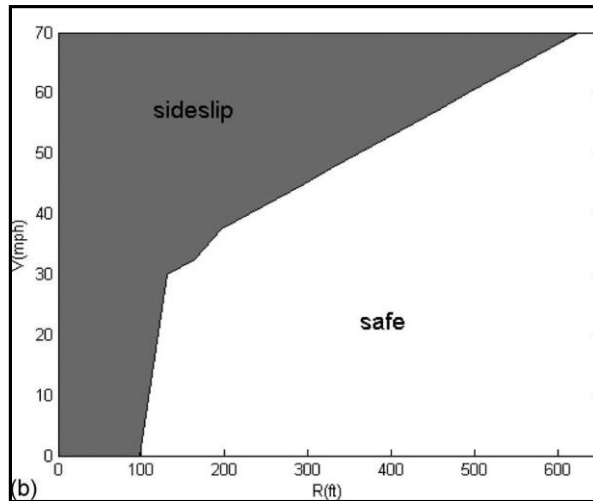


**Figure 2.7: Accidents on an ice-covered road**

*Source: Chen and Chen (2010)*

### **Critical Driving Speed on Curved roads**

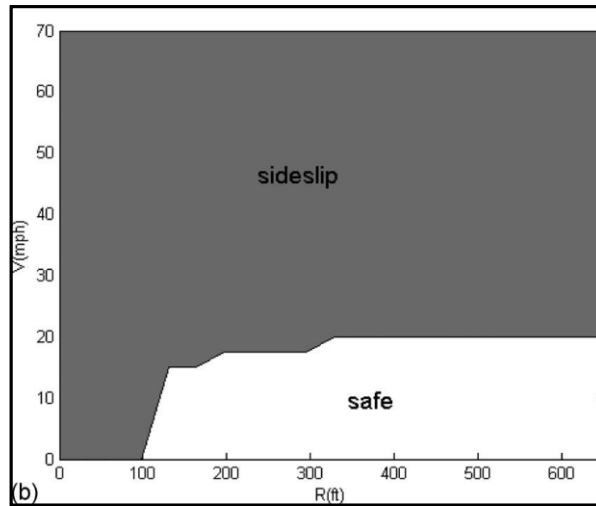
Figure 2.8 shows the relationship between different curve radii and CDS when the road is covered in snow. Sideslip accidents will most likely occur first. Depending on the driving speed, the curvature of 180 metres or lower with a wind speed of 32 km/hour will result in a sideslip accident.



**Figure 2.8: Road accidents and road curvature on snow-covered roads** *Source: Chen and Chen (2010)*

A comparison of the two figures shows that if the driving speed is more than 56 km/hour, and the radius of curvature more than 40 metres, sideslip probability increases dramatically when the wind speed increases from 0 km/hour to 32 km/hour.

Figure 2.9 shows that sideslip accidents will most likely happen to trucks if they are driven at a speed of 96 km/hour on a curved road with radius of 100 metres on an ice-covered road. The same results can be seen when a vehicle is driven at 40 km/hour on an ice-covered curved road with radius 40 metres. This shows that moderate wind can greatly affect the stability of a vehicle on ice covered curved roads. Once a sideslip accident occurs, there is very little a driver can do to stop the accident from occurring.



**Figure 2.9: Sideslip accidents at 100 metres road curvature**

*Source: Chen and Chen (2010)*

Although factors such as wind and slippery road surface were controlled in the simulation study, the transferability of results into a real life situation would be recommended. The simulation study aimed to emulate real life conditions as much as possible, therefore, only slight deviations from real environmental and driving conditions of trucks, emergency vehicles and Sport Utility Vehicles are expected.

In addition, to improve the safety of highways the following recommendations are suggested by Schuler (1940) for improving the road design, and thus road geometry

- It would be optimal to have separate roads for trucks which not only slow down traffic, but can damage the roads themselves.
- Schuler (1940) suggested that there should be four-lane divided highways, which run for 10 miles into the cities where congestion is likely to pile up.
- In order to increase the safety of the road, sight distances should be long enough for vehicles to see obstructions from afar (Schuler, 1940). Should passing be prohibited, it would be ideal to have shorter curves on the highway as drivers usually lose patience and end up taking risks.
- The super-elevation of the road should be increased on highways with high speed as it decreases the risk of accidents occurring (Schuler, 1940).
- With regard to curves that have high accident risk, the curves should be flattened out if possible to avoid impatient motorists that cause car accidents.

Most importantly there should be pedestrian areas where cars are strictly prohibited (Schuler, 1940).

## 2.5 Road Infrastructure

### 2.5.1 Pedestrian Infrastructure

The provision of infrastructure for both motorized and non-motorized traffic is important to avoid any conflict points. Due to the fact that pedestrians in South Africa constitute majority of non-motorized traffic, the risk of injury due to pedestrian-vehicle accidents is high. Avoiding this conflict can be done through the provision of pedestrian infrastructure, which separates the two forms of traffic

Gitelman et al., (2012) suggests that in Israel, pedestrians usually account for 8–10% of total traffic injuries and for more than 30% of the total fatalities in road accidents in Israel. His study aimed to diagnose infrastructure problems at a wide range of locations where concentrations of pedestrian accidents were observed, in order to identify infrastructure solutions that might improve pedestrian safety in Israel. The infrastructure variables included section/junction types, road types, crossing locations and type of town.

Accident data for the years 2006 to 2007 revealed that 6053 pedestrian injuries and 263 pedestrian fatalities were recorded. This is shown in Figure 2.10.

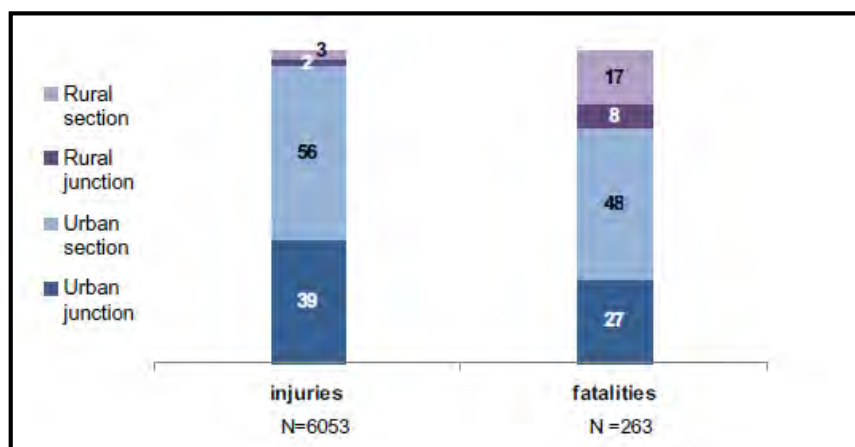


Figure 2.10: Pedestrian fatalities in Israel, according to accident locations

Source: Gitelman (2012)

An investigation into the Israel accident statistics further revealed that the majority of both fatalities and injuries occurred when a pedestrian crossed the road. Considering the locations where pedestrians crossed when the fatal accidents occurred (Figure 2.11), it can be seen that

49% of those pedestrians (n = 212), crossed a road section but not at a marked pedestrian crosswalk, whereas 22% crossed at unsignalized and 17% at signalized crosswalks. Among those who were injured when crossing the road (n = 4670), 50% of the cases occurred at un-signalized crosswalks and 28% when crossing a road. Among both fatalities and injuries, the elderly (ages 65 and older) had the highest rate per population in comparison with other age groups.

A black spot analysis of the pedestrian accidents was also performed. A sample of 14 Israeli towns were selected and pedestrian accidents were mapped and black-spots/areas were identified as follows: a junction or street “spot” (address) or street section up to 200 m in length (including junctions) where three or more pedestrian accidents occurred within three years. Gitelman et al., (2012) study found that black-spots of pedestrian accidents in urban areas, were short sections/junctions with a high accident concentration, most of the locations identified were intersections (signalized, non-signalized, roundabouts), with only some 16% of the sites situated on street sections. This finding is common for studies of accident concentrations in urban areas, where the accidents are typically “spread” over road sections/areas, thus, bringing a need for an area-wide consideration of the problem.

Intervention methods for decreasing the incidence of pedestrian fatalities are therefore important. These may include physical arrangements for pedestrians on street sections; mid-block crosswalk treatments; traffic-calming measures for collector roads; junction design; traffic calming measures for local streets; measures for traffic signals.

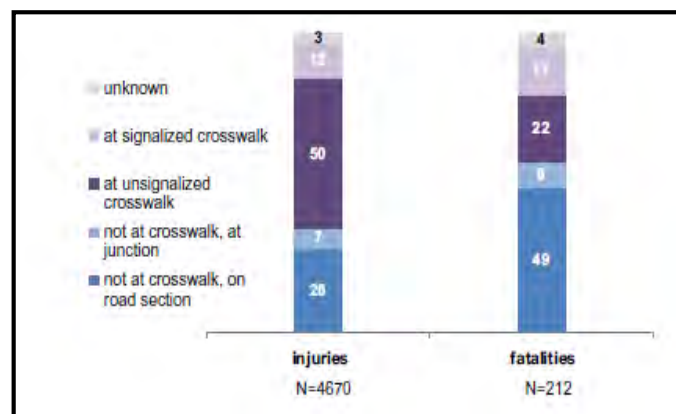


Figure 2.11: Pedestrian fatalities in Israel, according to location of crossings

Source: Gitelman (2012)

### **2.5.2 Infrastructure problems related to vehicular accidents**

An analysis of road accident data in Portugal revealed that infrastructural factors that influence the frequency of **urban** road accidents include traffic, lane balance, average lane width on major direction, average lane width on minor direction, the presence right turn lanes on major direction, the presence right turn lanes on minor direction, the traffic control devices, the total number of entering lanes on major direction being equal or higher than three, the number of lanes in both directions being equal or higher than four and the number of legs of the intersection (Gomes, 2013). This analysis was performed on road accident data for the years 2004 to 2007.

The variables associated with a decrease in the frequency of accidents were the number of legs with traffic in only one direction and the median presence on major direction. This study focused more on accidents on urban arterials, and not on rural highways. Therefore, the transferability of findings onto the rural setting is not applicable, as intersections and traffic controls are seldom found on rural highways.

In addition, the assumption that wider roads are of better quality, leads engineers to expect that improvements have a significant positive impact on road safety (Noland, 2003). However, the impact of there being a greater proportion of narrow single roadway roads (5–7 m) in the total road network of Spain (165787 km) was found to be a reduction in the number of fatalities (Albalade et al., 2013). This finding is expected, as a decrease in road space should result in a decrease in risky driver behaviour. However, having more single carriageway roads may also induce risky behaviour among motorists as overtaking opportunities are limited.

Under ideal circumstances, upgrading infrastructure is seen as a way of increasing road safety. Conventional traffic engineering is based on the assumption that ‘safer’ and ‘newer’ roads reduce road fatalities dramatically (Noland, 2003). This can be illustrated by the assumption that increasing a two-lane road to a four lane road, the risk of head-on collisions reduces. However, this risk is off-set by the fact that drivers travel at higher speeds on these new roads, thus resulting in no gains in safety (Noland, 2003).

The results of the model produced by Noland (2003) showed that the infrastructure improvements implemented have not provided any safety benefits. This analysis, using the negative binomial distribution, was done on accident data for the period 1984 to 1997. In fact,

the results show the contrary to what is expected and that additional lane miles are detrimental to road safety. The safety benefits were provided by other factors, such as improved medical technology, the demographic age mix of the population and reduced per capita alcohol consumption. Increasing the number of lanes also led to more fatalities and injuries. This was an unexpected result as a greater number of lanes would reduce the risk of head-on collisions as there would be more overtaking opportunities.

Increasing lane widths of roads is normally seen as an accident reducing strategy. States with arterials having road widths of less than 2.74 metres were shown, however, to have fewer road injuries as shown by Noland (2003). This finding is similar to Albalade et al, (2013), who found that single carriageways have fewer accidents than wider roads. When there are more arterial and collector roads with widths 3.65 metres or more, there is an increase in traffic related injuries and fatalities. This can be seen in the models produced. This result contradicts the general road safety practises which suggest increasing road safety by increasing lane widths. This contradiction could be explained by the fact that wider roads lead to increased driver carelessness.

Table 2-1 shows the variables that affect road traffic fatalities. It can be seen that variables with a negative coefficient result in a decrease in road fatalities, whereas variables with a positive coefficient result in an increase in fatalities.

**Table 2-1: Variables affecting road fatalities**

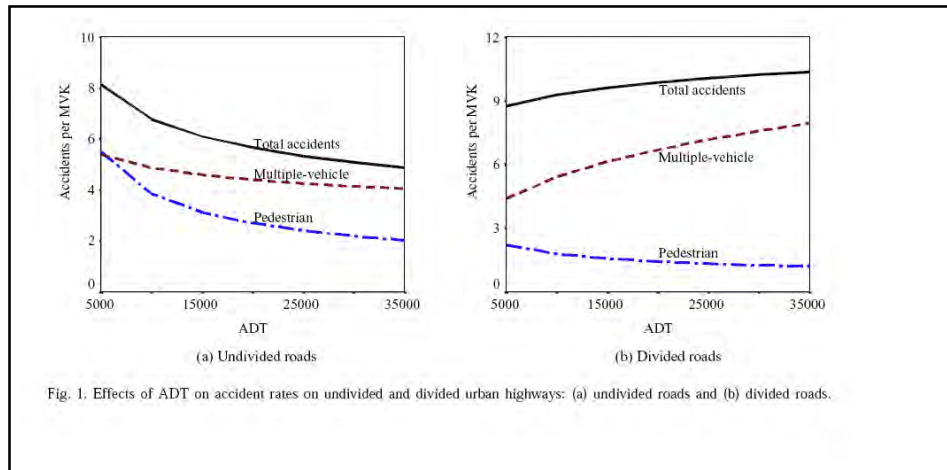
	A		B		C			
	Deaths (1984-1997)		Injured (1984-1997)		Deaths (1985-1997)		Injured (1985-1997)	
	Coefficient	t-statistic	Co-efficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
<b>Infrastructure variables</b>								
Log(total lane miles)	0.355	3.16	0.624	4.55	0.378	2.83	0.183	1.17
log (average number of interstate lanes)	0.173	0.69	2.524	6.23	0.253	0.96	2.843	6.87
log (average number of arterial lanes)	0.101	0.91	0.506	2.09	0.101	0.84	0.494	2.35
log(average number of collector lanes)	1.036	2.61	-0.713	-0.73	1.271	2.47	-1.246	-1.41
log (interstate lane miles %)	0.052	0.61	-0.204	-1.6	0.061	0.66	-0.367	-2.81
log (arterial lane miles %)	0.152	1.92	0.238	1.7	0.132	1.47	0.103	0.74
log (collector lane miles %)	0.149	2.07	0.304	3.32	0.125	1.62	0.205	2.26
log (arterials with lane widths of 9 ft or less %)	0.007	1.44	-0.021	-2.68	0.006	1.16	-0.011	-1.48
log (arterials with lane widths of 10 ft %)	-0.017	-1.6	-0.035	-2.41	-0.017	-1.52	-0.033	-2.33
log ( percent arterials with lane widths of 11 ft %)	-0.003	-0.24	-0.011	-0.67	-0.003	-0.21	0.003	0.24
log ( arterials with lane widths of 12ft or greater %)	0.005	0.09	0.133	1.24	0.034	0.54	0.075	0.67
log (collectors with lane widths of 9ft or less %)	-0.022	-3.06	-0.034	-2.92	-0.022	-2.67	-0.023	-2.19
log (collectors with lane widths of 10 ft %)	0.025	1.39	-0.015	-0.51	0.011	0.55	-0.008	-0.28
log (collectors with lane widths of 11 ft %)	-0.023	-2.54	-0.044	-3.5	-0.024	-2.34	-0.031	-3.18
log (collectors with lane widths of 12 ft or greater %)	0.033	1.21	0.008	0.14	0.048	1.59	0.027	0.42
<b>Demographic and trend variables</b>								
log (population aged 15-24 years %)	0.566	5.87	0.646	4.14	0.621	5.99	0.749	4.8
log (population over 75 years %)	-0.322	-3.19	-0.518	-3.46	0.366	-3.22	-0.219	-1.34
log (per capita income)	0.955	8.05	0.953	4.27	0.877	6.71	0.73	3.13
log ( population)	0.119	1.35	-0.471	-4.26	0.148	1.4	0.045	0.31
Year	-0.01	-2.9	0.005	0.89	-0.003	-0.85	0	-0.02
<b>Other variables</b>								
Primary seat-belt law	-0.047	-3.2	-0.048	-1.54	-0.039	-2.39	-0.103	-3.16
Secondary seat-belt law	0.022	2.27	0.013	0.67	0.006	0.54	0.011	0.54
log (per capita alcohol consumption)	0.49	5.67	0.103	0.65	0.417	4.52	0.147	0.95
log (white infant mortality)	-	-	-	-	0.13	2.67	0.013	0.18
log ( hospital per square mile)	-	-	-	-	0.136	1.61	-0.617	-6.54
Constant	13.074	2.23	-19.746	-1.94	-0.162	-0.02	-12.784	-1.06
N	700		657		646		607	
log likelihood	-3290.75		-6029.45		-3007.16		5510.2	

*Adapted from: Noland (2003)*

In comparison to the above, African countries are considered less developed, and hence always lag behind when it comes to infrastructure development for road safety. Road traffic safety poses a major problem for developing countries, such as Ethiopia.

The importance of proper infrastructure planning can be illustrated in, Addis Ababa. It is a city that has seen tremendous growth in recent times but is, somehow, growing without proper planning and control, which has resulted in mixed-up land uses (Berhanu, 2004). This has affected the road network of the city which is not adequate to meet the requirements of its growing traffic needs. Traffic controls, signals, road markings as well as pedestrian facilities

are not in place. The under-developed roads, as well as the risky behaviour of pedestrians, have resulted in the occurrence of many road accidents. The arterial roads in the city have been the major contributor of many road accidents. Investigating the relationship between traffic accidents as well as road infrastructure could assist road authorities in reducing the number of fatal accidents in the city.

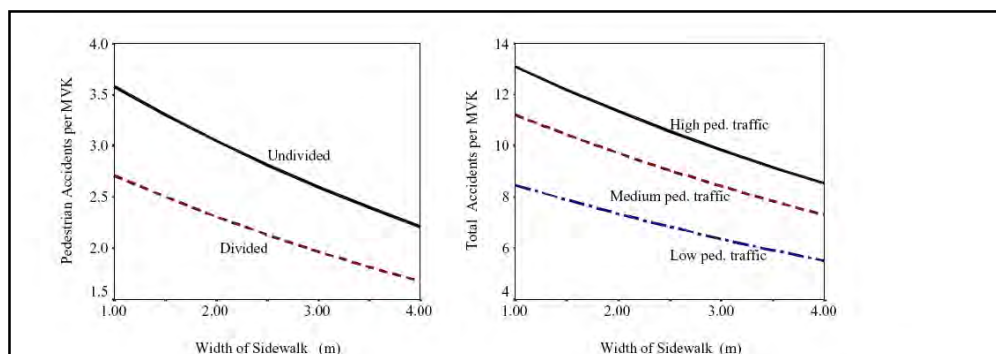


**Fig.2.12: ADT on dual and single carriageways**

*Source: Berhanu (2004)*

Figure 2.12 shows that all types of accidents decrease when Annual Daily Traffic (ADT) increases on undivided roads (single carriageway). With divided roads (dual carriageways), total accidents and multiple-vehicle accidents increase with an increase in ADT.

It was also found that in order to increase pedestrian safety, increasing the width of the sidewalk can greatly decrease pedestrian accidents. This relationship is shown in Figure 2.13.



**Figure 2.13: Pedestrian accidents against width of sidewalk**

*Source: Berhanu (2004)*

Increasing the sidewalk width and paving the sidewalks reduces the probability of pedestrian accidents as pedestrians are less inclined to walk in the road.

It can thus be said that poor road infrastructure leads to road traffic accidents. Improvements can be in the form of raised kerbs, wider and paved sidewalks, which ultimately reduce pedestrian accidents and improve traffic safety. Roads with higher ADT typically have higher accidents for all types of highways. There is an increase in multiple-vehicle accidents as well as total accidents (Berhanu, 2004). This result is in contrast to what is expected, as higher ADT would result in more congestion, which usually prompts motorists to be cautious on the road.

As the above literature suggests, infrastructure has a significant effect on road fatalities. The provision of infrastructure requires proper planning as effects of not providing the necessary infrastructure may be detrimental. Engineers should not solve problems by just increasing road capacity and lane widths, as the effects may be off-set by careless driver behaviour. Traffic calming measures should be considered at locations where pedestrians are vulnerable, as well as re-designing of roads at sections that are known black spots.

## **2.6 Traffic Calming**

Infrastructure measures can be used to improve road safety. Traffic calming is an example of infrastructure measures adopted in Europe and have since played a huge role in the reduction of road accidents (Vanderschuren and Jobanputra 2009).

Traffic calming measures can either be volume control measures which address cut-through traffic problems by preventing certain movements, thus diverting traffic into streets that can better accommodate the traffic. Speed control measures address speeding problems by changing the vertical alignment, horizontal alignment or narrowing the roadway (Vanderschuren and Jobanputra 2009). For the purposes of road safety, speed control traffic measures will therefore be discussed frequently.

Various speed traffic calming measures can be employed to reduce road accidents thus increasing road safety. These speed control measures include speed humps, speed cushions, rumble strips and raised intersections. These types of infrastructure measures achieve their purpose by causing vertical deflection of vehicles. Horizontal deflection measures such as

traffic circles, roundabouts and chicanes can also be employed. Otherwise, posted speeds and warning signs can help improve speed control (Vanderschuren and Jobanputra 2009).

In most developing countries, the most vulnerable road users tend to be pedestrians, cyclists, and passengers in buses, minibuses and trucks. It would, therefore, be useful for developing countries to use less-costly speed reducing measures such as traffic calming measures. According to a study conducted by (Afukaar 2003), rumble strips installed on the main Accra-Kumasi at the Suhum Junction have led to a 35% reduction in crashes and a 55% reduction in fatalities during the period January 2000 and April 2001.

The Department of Transport and the Transport and Road Research Laboratory in the UK revealed that reducing traffic speeds and volumes tend to reduce severity of the vehicle accidents, especially those involving pedestrians and cyclists (Vanderschuren and Jobanputra 2009)

A study in the US revealed that speeds were reduced by 23% for humps, 11% for circles and 4% for road narrowings. Other independent studies have revealed that road-based traffic calming measures that result in a speed reduction of 14.4 km/h reduce traffic accidents by 60 to 70%. They also revealed that fatal or serious injuries were also reduced when such measures were applied (Vanderschuren and Jobanputra 2009).

Roundabouts seem to have the most desirable effect on traffic safety, particularly accidents involving injuries (Vanderschuren and Jobanputra 2009).

Traffic calming measures can be implemented worldwide as it is a soft engineering approach and it increases the safety of pedestrians and drivers alike.

## **2.7 Collection of road accident data**

Traffic data is collected at every stage of project development in order for roads to be planned, designed, constructed, maintained and operated more rationally and scientifically. It is also collected in incidences involving road accidents.

Thwala (2012) revealed that in South Africa, the most common problem faced by transport researchers is the frequency of poor quality data. However, this is not a problem experienced in South Africa alone, as many developing African countries have such issues. This poor quality data could be 'randomly missing, uninformative, partially informative, or even

misleading' (Thwala, 2012). Incomplete Road Traffic Accident (RTA) data could be caused by administrative error, defective technique, or technology failure.

It is a well-documented fact that motorists have a legal obligation to report collisions in which their vehicles are involved. However, in developing African countries and developed countries, there exist crash data discrepancies involving non-reporting and under-reporting of road traffic accidents.

Salifu et al. (2011) revealed that all crashes involving fatalities were reported in an investigation of road accident data in Ghana during the period 1997 to 2004. However, the less severe the crash consequence, the higher the likelihood of non-reporting of accidents to the police (Salifu et. al, 2011).

The study also indicated that night-time is generally associated with a higher non-reporting rate (87 out of 94 accidents) than the daytime (163 out of 466 accidents). This could be due to the decreased movement of vehicles and decreased presence of law enforcement. Drivers cited that the reason for their non-reporting of single-vehicle collisions was that the crash did not involve any other vehicle (Salifu et al., 2011). In such cases, drivers may opt to fix the vehicles themselves if no fatalities occurred. This also depends on whether motorists have vehicle insurance or not, the driver may opt not to report any occurrence of single vehicle collisions and pay for the vehicular damage themselves.

With respect to crashes involving multiple vehicles, the drivers preferred reaching a mutual agreement to repair their damaged vehicles than to reporting the crash to the police. This was found to be the case with 103 out of 117 of the respondents.

The occurrence of under-reporting in the urban environment occurred 41% of the time and 36% of the time with respect to the rural environment. This situation may be due to the fact that non-urban crashes were more severe and were most likely to be reported.

The most probable reasons for under-reporting from drivers and casualties were: did not involve other vehicles, mutual agreement to repair damaged vehicle/s, lack of knowledge of the legal obligation to report a crash and proximity of police station to the place of crash.

It is important to capture road accident data for statistical and analytical purposes. Therefore, providing education campaigns to people, and making the process of reporting accidents efficient, would encourage more reporting of road accidents, regardless of severity. Also,

training police officials to record road accident data efficiently in a centralized system, or dispatching officials to accident scenes immediately, would allow for the immediate and accurate capturing of road accident data.

## **2.8 Collection of data in a road safety audit**

Road safety audits are a cost effective way to evaluate rural highways in which highway accident data is scarcely available.

Extensive research on the procedural methods of a road safety audit was done prior to undertaking a road safety audit on the N1 highway. This was in the form of a literature review and other available online resources. The literature review revealed that a similar study had been conducted in Cameroon by Bhatiti et al. (2010) while investigating road traffic accidents in the Yaounde-Douala road section, a rural highway in the outskirts of Cameroon.

Cafiso et al., (2005) suggested that the main requirements for **team members** to actively participate in a road safety audit are independence and qualification. According to Cafiso et al (2005) ‘independence from the design, maintenance and operation’ of the road to be reviewed is needed. Cafiso et al. (2005) suggested that a team of reviewers was to comprise ideally of a minimum of three people, with diverse backgrounds and capable of providing an objective opinion during the site investigations (Cafiso et al., 2005). The three reviewers include the driver, front seat reviewer and back seat reviewer.

The road inspection was to be conducted taking the following factors into consideration:

- A preliminary inspection conducted during the day time, in order to understand the general road safety conditions and its relationship with surrounding land use, terrain and the road network. (Cafiso et al., 2005)
- General inspection of the road, conducted during the daytime, examining the general safety concerns along the road segments. (Cafiso et al., 2005)
- Detailed inspection performed during the daytime, which aims to provide a detailed inspection of the safety concerns associated with specific site (Cafiso et al., 2005)
- A night-time inspection, which aims at analysing the driving experience and road perception without natural lighting (Cafiso et al., 2005). This was excluded as part of the investigation due to time constraints and lack of resources to perform the task.

The main aim of the **preliminary inspection** to be performed by the researcher according to Cafiso et al, (2005) was to investigate how different road users experience the road environment of a particular road. The analysis not only observes the road, but also how the adjacent environment interacts with the road and road users. (Cafiso et al., 2005)

According to Cafiso et al (2005), the preliminary inspection was to be conducted on a stretch of road not more than 100km in length. Equipment to be used included, a GPS receiver and a digital camera. The method of inspection included driving along the road in both directions.

It is usually necessary to run the road at the lowest permissible traffic speed on a highway, in order to take note of all the aspects affecting the road environment. It is the duty of the driver to note any corrective driving manoeuvres that he performed (Cafiso et al., 2005). The GPS receiver is used to geo-reference any useful points on the road such as kilometre posts and intersections. For the research topic conducted, the driver maintained a driving speed of 60 km/h.

Cafiso et al., (2005) suggested that the primary objective of the **general inspection** was to retrieve important information about any safety concerns associated with a particular road, and their locations along the route. The general inspection also utilizes a digital camera, with the front and back seat reviewers compiling **checklists** necessary for the road audit. The road is to be traversed in both directions, at low speeds. The driver also takes note of any corrective manoeuvres he performs every 100m (Cafiso et al., 2005). The **checklist** provided by Cafiso et al. (2005) related mainly to the main safety features which are usually present in continuity along two lane roads. The checklist procedure was to be completed in both the directions (to and from) traversed during the audit, by both reviewers in the front and back seat. It was separated into two parts, Part A which is compiled on site during the road inspection, and Part B, which is compiled during the subsequent video examination. (Cafiso et al., 2005). This checklist is provided in Appendix A.

## **2.9 Case studies of road accidents in African cities (A look at Cameroon)**

A case study conducted by Bhatti et al (2010) aimed at investigating the cause of road accidents in Low and Middle-Income Countries (LMIC). LMIC's in Africa had the highest road fatalities as of 2007, with 32.2 fatalities per 100 000 inhabitants (WHO, 2009). Bhatti et al., (2010) investigated the Cameroonian case, which has a total road network of 50 000 km in length, with only 10% of the network being paved. The Yaounde-Douala road section

(National Road 3), with total length 243km has the heaviest Annual Daily Traffic (ADT) and passes through several small towns (Bhatti et al, 2010).

The investigation was carried out through site visits. A coding sheet was used for data collection on built-up or rural areas, horizontal and vertical profiles, road widths, surface regularity, verge slope, depth at 10m from verge, location and type of nearby obstacles (at a 50m radius), horizontal markings and presences of intersections were recorded (Bhatti et al., 2010). Sites were chosen through GPS locating and video-recording.

The recorded data by the authors gave information on number of lanes, side markings, presence of road drain, type of intersection (four-legged, three-legged, and access), intersection control (sign, signals), intersection treatment (speed calming, improving visibility by angling the entering side road), speed control measures (speed sign, hazard sign, road sign with rumble strips), the maximum in both directions of the length of the straight section (the length of closest straight section if the site is on a curve), important structures (housing and other non-shop-buildings, shops, toll plaza). The information obtained from the video recording, therefore, gave insight into the infrastructural and geometrical aspects of the national road.

Variables collected both during the site visit and from the video recording showed that accident sites were more likely to be located on a flat road profile, with an irregular surface condition and near solid obstacles (within 54 m) , and at three- and four-legged intersections when a model was produced. This may be due to the facts that nearby obstacles (within 54 metres) worsen the severity of accidents of errant vehicles as they may be situated on the road reserve. The obstacles block the driver's view and increase the vulnerability of occupants when an accident occurs (Bhatti et al., 2010). Removal of these obstacles should be considered if financially feasible, or soft engineering measures should be implemented in such accident prone areas.

The likelihood of collisions increased in built-up areas when verge depth was 0 m (flat) as compared to verge depth more than 0 m (inclined). The model produced by Bhatti et al., (2010) also showed that the likelihood of accidents on flat road sections increased when the road was wider than 8 m as compared to narrower road sections. This result is expected, as the authors (Noland, 2003; Albalade et al, 2013) have shown that an increase in lane width results in a higher occurrence of road fatalities. This is again due to the increased risky behaviour of motorists due to more road space.

The results of the investigation thus showed infrastructural and geometrical features that were associated with crash sites on this 243 km Yaounde'– Douala road section. These included flat road profiles, irregular surface conditions, nearby road obstacles and three- and four-legged intersections. The likelihood of accidents increased with built-up areas in plain regions. This may be exacerbated by driver fatigue from a monotonous driving environment (Thiffault et al, 2002; Frank et al, 1994).

## **2.10 Hazardous location analysis in the Western Cape**

South Africa, has one of the highest fatality rates with respect to road accidents. These fatalities tend to affect all categories of road users, namely motorists, pedestrians and to a lesser extent, cyclists. Worldwide, most victims tend to be pedestrians, and most likely, the breadwinners (Vanderschuren and Jobanputra, 2011). Developing countries (which include low and middle income countries) tend to experience, significantly, higher road accident rates than high income countries. In 2002, low and middle income countries accounted for 90% of all road traffic deaths (Vanderschuren and Jobanputra, 2011) The reason for such a phenomenon affecting mostly the developing nations is that inadequate infrastructure does not cater for pedestrian movement in countries, such as South Africa, whereas, most road users travel by foot (more than 50% of South Africans complete their trips by walking) or public transport. Sometimes, pedestrians are forced to use the infrastructure that is, specifically, designed for vehicular movement, thereby increasing their risk to car accidents.

As of 2006, South Africa was the fourth highest generator of road fatalities with a record of 27.97 fatalities per 100 000 inhabitants (Vanderschuren and Jobanputra, 2011). However, a 2009 report by the Road Traffic Management Corporation revealed that South African fatalities per 100 000 inhabitants were 27.91 and that Western Cape had 23.99 fatalities per 100 000 inhabitants. This shows that there has been a slight decrease in National fatalities over the years; however, the percentage of fatalities is still too high to be acceptable.

This study also serves to compare and contrast road accidents in South Africa with those in the Western Cape, with a concentrated focus on road accidents in the Western Cape.

Gender seems to play a significant role in determining the statistics and nature of road accidents in the Western Cape. Females are involved in far less accidents when compared to their male counterparts. As drivers of vehicles, they account for approximately 8% of road accidents. However, females involved in traffic accident deaths as passengers are a staggering

45%. This number is mainly, due to the fact that females become vulnerable and are dependent on the driver's road behaviour when they are passengers. Nevertheless, it is clear that females are safer drivers than males (Vanderschuren and Jobanputra, 2011).

The population group in the Western Cape is dominated by the Coloured community which comprises 50% of the population, Black Africans – 25%, Whites approximately 20% and Asians and others are included in the remaining 5% (Vanderschuren and Jobanputra, 2011).

From data collected in 2007 by the Provincial Government of the Western Cape database, iPas, it is clearly shown that the White community was involved in 43% of road accidents and the Coloured community 40%. As the White community just comprises about 20% of the Western Cape population, they were involved in a significantly higher accident rate than their share in the Western Cape population. This can be explained by their high economic activity and high car ownership rate (Vanderschuren and Jobanputra, 2011). The Black community which had 15.3% of the crashes and the Coloured community were involved in fewer crashes in proportion to their population. Again, this can be explained by their lower economic activity and low car ownership rate (Vanderschuren and Jobanputra, 2011)

In terms of fatalities, even though the White community is involved in 43% of accidents, their fatalities make up 19% of the total fatalities in the province. Coloureds however, reportedly make up 50% of the road fatalities. Among the male victims, coloured males made up 51.8% of the fatalities (Vanderschuren and Jobanputra, 2011).

The female statistics differed somehow. White females were involved in the most accidents (61.7%) followed by Coloured females (29.4%). When analysing the fatalities, coloured females comprised the majority of road deaths at a staggering 53.5%, followed by black females at 27.9% (Vanderschuren and Jobanputra, 2011).

Driver fatalities indicate that even though females are involved in 25% of accidents, their fatalities stand at 8% with White females being the most likely victims at 70% of reported accidents. Again, Coloured male drivers make up most fatalities at 45% of all males and 40% of all driver fatalities. They are closely followed by White males, which make up 33% of all male accidents and 30.4% of total driver fatalities in the Western Cape (Vanderschuren and Jobanputra, 2011).

An analysis of road types carried out revealed that a high number of accidents occurred on single-carriageways and that in 40% of all accidents, a barrier line was missing. However,

some of this data cannot be clearly proven to apply to the Western Cape and further analysis is planned for in future research (Vanderschuren and Jobanputra, 2011).

In terms of days in which accidents are most likely to occur, fatal accidents are most likely to happen on Weekends (Friday, Saturday and Sundays). However, accidents may occur throughout the week (Vanderschuren and Jobanputra, 2011).

The time of day also is a factor that contributes to the number of accident occurrences. Forty percent of collisions with animals are at night on unlit roads. Similarly, 30% of single vehicle overturning incidences occur at night and 53% of accidents with fixed objects happen at night under unlit conditions (Vanderschuren and Jobanputra, 2011).

## **2.11 Black spot identification**

The crux of civil engineering involves providing a service to the civil society. It can therefore be said that the loss of lives, which can be prevented through proper infrastructure planning, is a disservice to the civil society. Identification of black spots is important to prevent and provide remedial measures in those specific locations.

Flahaut (2004) suggested that in places where there is an abrupt observed change in speed, the area might potentially be a black spot. Potentially hazardous locations, such as ‘sharp curves, narrowing roads, minor crossroads and agglomerations in roads’ were observed to be significant variables in black spot identification. In these environments, warning signs are more suitable so that the risk of accidents, due to the transitions in speed, is reduced (Flahaut, 2004).

In identifying black spots, Flahaut (2004) also suggests that major at grade junctions seem to be a risk factor and cause numerous accidents. Flahaut (2004) suggests that intersections should rather be changed to roundabouts to make them safer. In comparison with other intersections, Flahaut (2004) suggests that roundabouts are known to improve safety by fluidizing traffic flows and making accidents less severe.

Identification of black spots appears to be an important aspect of highway design. This is usually done by statistical analysis of accident data. However, a simpler method of identifying blackspots was suggested by Gitelman et al. (2012) in his study of fatal pedestrian accidents.

Pedestrian accidents were mapped using co-ordinates and geographical data. Black-spots/areas were identified as follows: a junction or street “spot” or street section up to 200 m in length (including junctions) where three or more pedestrian accidents occurred within three years (Gitelman et al, 2012). This method of black spot identification is easy to apply and implement, as any accident type involving three or more fatal accidents in a three year period can be identified as a black spot, provided that the section is 200m in length. Depending on the length of road section, linear interpolation can be applied to the length of road section to investigate whether the section is a black spot. The explanation can further be adapted to include accidents that may or may not be fatal in nature, as long as serious injuries occur.

Argawal et al, (2013) developed a framework for identification of hazardous locations using the Analytical Hierarchy Process (AHP). The methodology presents a hierarchical structure for identification of safety factors. Road safety hazardous conditions are decomposed into safety hazardous condition at straight sections, safety hazardous condition at curve sections and safety hazardous condition at intersections. Analytical hierarchy process (AHP) is used to determine the weight of the different identified safety factors. The higher the value of the Safety Hazardous Index at a particular location indicates more hazardous locations in the road network.

A framework for ranking hazardous locations is presented in the following figure 2.14

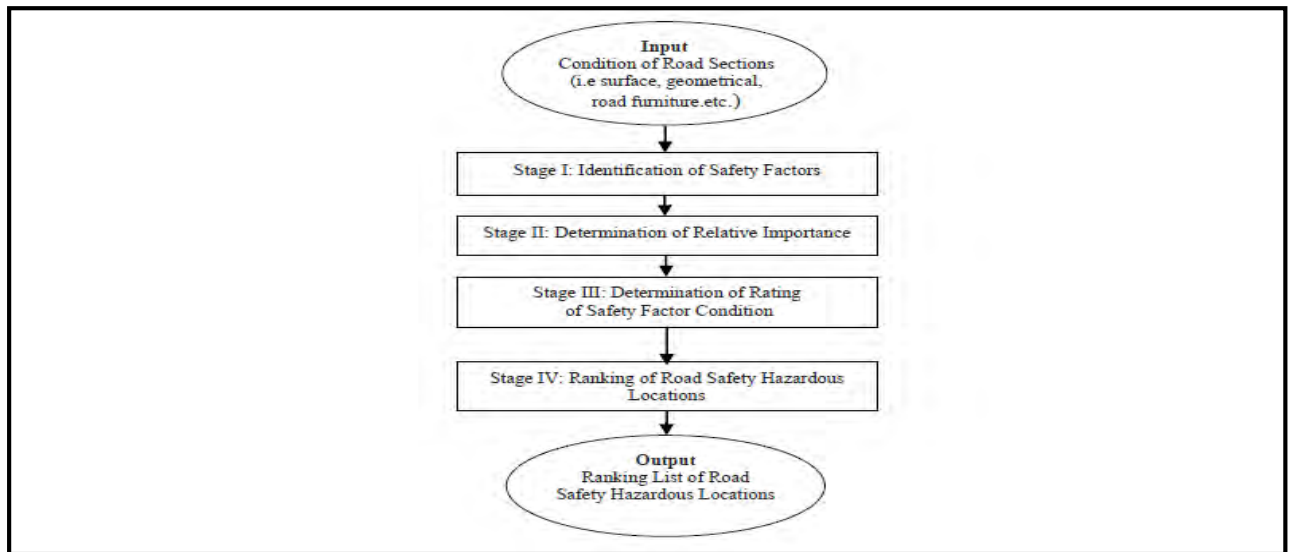


Figure 2.14: Framework for the proposed methodology for Ranking Road Safety Hazardous Locations

Source: Argawal et al., 2013

Safety factors are also identified using a hierarchical process that is shown in figure 2.15:

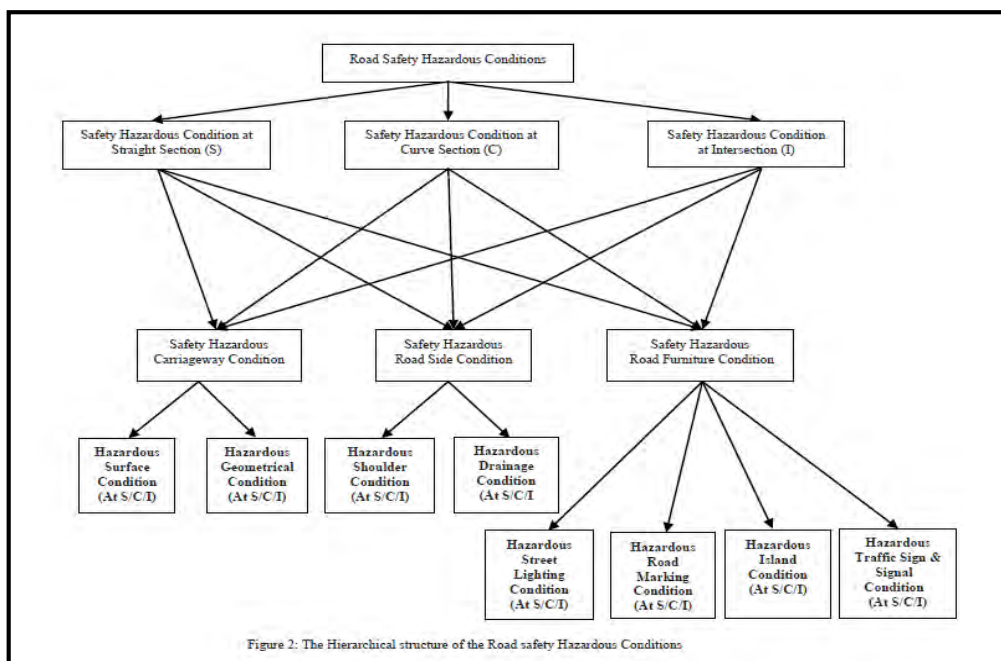


Figure 2: The Hierarchical structure of the Road safety Hazardous Conditions

Figure 2.15: The Hierarchical structure of the Road Safety Hazardous Condition Source: Argawal et al., 2013

The relative importance of safety factors is also important in the hierarchical structure. Table 2.2 allocates the relative importance of the different road safety factors.

As can be seen from Table 2.2, Hazardous Surface Conditions, as well as Hazardous Geometrical Conditions are allocated the highest factors. Accidents occurring at intersections have the highest share of the weighting, followed by accidents at curved sections and then accidents at straight sections.

In this method, Argawal et al., (2013) also requires the condition rating of the different safety factors. Argawal et al., (2013) suggests that a 0 rating represents no deviation from standard condition and 1 represents a very poor quality.

**Table 2-2: Weighting of Safety Factors for Straight Section, Curved Section and an Intersection.**

S No	Name of Safety Factors	Straight Section (SFS)	Curve Section (SFC)	Intersection (SFI)
1	Hazardous Geometrical Condition	0.027	0.0675	0.17
2	Hazardous Surface Condition	0.033	0.0825	0.19
3	Hazardous Shoulder Condition	0.0114	0.0228	0.07
4	Hazardous Drainage Condition	0.0086	0.0172	0.04
5	Hazardous Street Lighting Condition	0.0075	0.0175	0.0363
6	Hazardous Road Marking Condition	0.0051	0.0119	0.0242
7	Hazardous Island Condition	0.0016	0.014	0.029
8	Hazardous Traffic Sign and Signal Condition	0.0158	0.0266	0.0705
	Total of Weights	0.11	0.26	0.63

*Adapted from: Argawal et al., 2013*

For a straight section, the Safety Hazardous Index is determined as follows

$$SHIs = \sum_{SF} Wsfs \times Rsfs$$

SHIs=Safety Hazardous Index at Straight Section

Wsfs=Weight of safety factor at Straight Section

Rsfs= Condition rating of safety factor at Straight Section

For a curved section:

$$SHIc = \sum_{SF} Wsfc \times Rsfc$$

Where:

SHIc=Safety Hazardous Index at Curved Section

Wsfc=Weight of safety factor at Curved section

Rsfc= Condition rating of safety factor at Curved section

For an intersection

$$SHIi = \sum_{SF} Wsfi \times Rsfi$$

Where:

SHIi=Safety Hazardous Index at Intersection Section

Wsfi=Weight of safety factor at Intersection section

Rsfi = Condition rating of safety factor at Intersection section

To determine the safety hazardous index of an entire road section, the summation of all Safety Hazardous Index is required as follows:

$$SHIrs=SHIs + SHIc +SHIi$$

Where:

SHIrs= Safety Hazardous Index at Entire Road Section

SHIs= Safety Hazardous Index at Straight Section

SHIc= Safety Hazardous Index at Curved Section

SHIi= Safety hazardous index at Intersection Section

It can therefore be said that a high Safety Hazardous Index at a certain location would indicate the presence of many hazardous locations at that particular section of road. This section would then be classified as a black spot.

This method suggested by Argawal et al., (2013), although intensive and human dependent, presents an alternative to statistical analysis. It requires the analyst to have a deeper knowledge of the road section being reviewed. It also gives the analyst an opportunity to have a visual perspective of the defects and potential hazardous locations of the road section under investigation.

## 2.12 Chapter summary

In this chapter, various research publications were reviewed. The literature suggested that road accidents were caused by deficiencies such as poor visibility, slippery pavements or due to loose gravel among many other infrastructural deficiencies. It also highlighted the risk that foreign nationals face when driving in unfamiliar driving environments, and these accidents were more likely to occur with rented vehicles.

The literature also highlighted factors that affect road accidents, with human factors being cases of drunken driving, and vehicular factors being cases of defective steering and transportation of heavy metalworks, which pose as a safety risk in cases of accidents.

The importance of legislation was also investigated, with measures such as speed limits, police enforcement and traffic calming being more effective in developing African countries.

Chen and Chen (2010) showed that single-vehicle accidents occur more in harsh driving conditions, such as rollover or sideslip accidents which occur mostly on rural roads. Wind effects are also believed to affect the occurrence of single-vehicle overturning accidents.

Several methods of improving the safety of highways were suggested through geometrical changes. These included 4-lane divided highways, shorter length curves on highways to decrease risk-taking, increased super-elevation to reduce vehicle speeds. All these measures should increase the safety of the road.

Other infrastructure improvements suggested by Vanderschuren and Jobanputra (2009) were traffic calming measures such as speed humps, and road-narrowing.

The issue of under-reporting and non-reporting was also investigated by Salifu et al. (2011) and it was shown that fatalities are mostly always reported and that the less severe the accident, the higher the likelihood of non-reporting as people are unlikely to know about their legal obligation to report accidents.

The chapter then concludes with a case study conducted in Cameroon on a road, with a high ADT. The investigation was carried out through site visits and collection of data using coding sheets and video surveillance. The information found included data on road widths, surface irregularities and road profiles. The video footage included data on intersections, road markings and road drainage. Another Western Cape case study conducted by Vanderschuren

and Jobanputra (2011) on black spot analysis in the Western Cape is included in the literature, as well as a black spot identification methodology by Argawal et al., (2013).

In light of the above sections, the following factors pertaining to the research topic can be highlighted.

The geometry in terms of lane width, existence of a median, and existence of side accesses are variables that are important when performing road safety audits of rural highways. Road infrastructure in terms of paved shoulders is particularly important in preventing passenger vehicles from veering off the road. These geometrical and infrastructural factors are relevant to the N1 highway study. Other factors that are relevant towards improving the safety of highways include the driving environment, which can exacerbate fatigue when driving.

The case study conducted by Bhatti et al., (2010) in Cameroon (on a rural highway) also forms an important basis for the research of the N1 highway, as it shows that **flat road profiles, irregular surface conditions** as well as **road obstacles that are in close proximity** contribute towards making a road section a hazardous location. These findings can also be investigated in the South African N1 highway case between Laingsburg and Beaufort West to determine if the same findings are applicable.

## **3. Research Methodology**

### **3.1 Introduction**

This chapter presents the procedure followed in the research design. The main elements of achieving the research objectives are shown in figure 3.1. The flow chart indicates the procedure followed from the start of the thesis, followed by the research proposal, as well as the research design followed to complete the thesis.

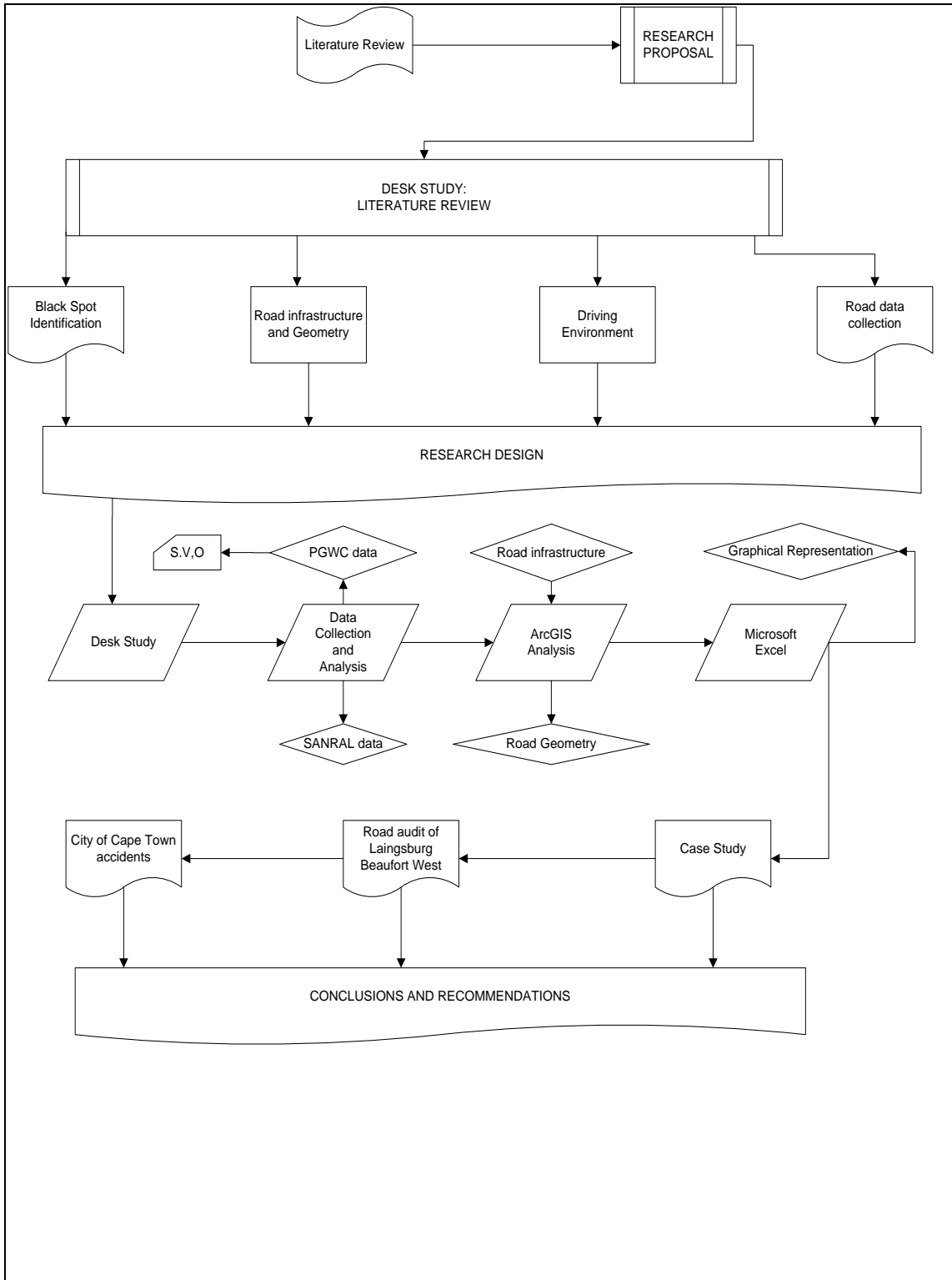


Figure 3.1: Flow chart showing the different research methodologies used and data analysis methods

## **3.2 Desk Study**

### **3.2.1 Literature Review**

An extensive literature review detailing existing work that has been done on road accident factors was undertaken. The existing body of literature placed emphasis on factors such as road condition, road environment and human factors such as drunk driving, which may ultimately lead to fatal accidents. Problems such as infrastructure and geometry were discussed, as mentioned in Chapter 1.

The literature review also gave the researcher insight on data collection methods, and gave the researcher theoretical knowledge that made the research design to be centralized. The literature also gave insight into a hazardous location analysis that was performed throughout the Western Cape in 2011.

An important aspect of the literature review was the obtaining information on how to perform road safety audits on highways.

## **3.3 Data collection**

### **3.3.1 PGWC geographical data**

The Provincial Government of the Western Cape provided geographical data on fatal accidents in the Western Cape Province. This data was specifically for the years 2000 to 2007 and was retrieved from the iPas system. The data, however, did not include geographical information on the City of Cape Town municipality. The Laingsburg-Beaufort West N1 highway was the primary study area. Analysis of the data for infrastructure and geometrical variables which influence single vehicles overturning accidents in this road section, was the primary objective of the research.

### **3.3.2 SANRAL data**

The South African National Road Agency Limited also provided geographical data on fatal accidents which occurred in the City of Cape Town municipality. This data, however, did not include information on accident types and road conditions at time of accident. This part of the research was conducted as a secondary investigation, which included identifying potential hazardous locations within the municipality which may be

considered for future research. It was also included to evaluate whether the PGWC has achieved the goal of accident reduction of 50% by the year 2014.

## **3.4 ArcGis Analysis**

### **3.4.1 Accident type analysis**

The ArcGis 10.1 software package was used to map the geographical data. As already mentioned in Chapter 3.3.1, the study area was between Laingsburg and Beaufort West. Mapping of the geographical data allowed for the analysis of the accident type, with the aim of comparing the frequency of single vehicle overturning accidents with other accident types. This is shown in Appendix B. Analysis of the accident data would also assist the researcher in determining whether the geographical data was sufficient to determine the factors that influence the single vehicle overturning accident type.

### **3.4.2 Infrastructure analysis**

ArcGis was used to analyse the infrastructure conditions at the single vehicle overturning accidents locations. The following factors were considered when analysing the infrastructure:

- Road markings
- Road signs
- Obstructions on the road
- Presence of a barrier line

The infrastructure analysis aimed to achieve the research objectives posed in Chapter 1, which included determining whether infrastructure has an effect on the frequency of road accidents on highways.

### **3.4.3 Geometrical conditions analysis**

Geometrical conditions of the road were also analysed using ArcGIs and could be displayed in a map. These geometrical conditions, which are important to the driving experience include:

- Road surface
- Road grade
- Type of junction
- Built up area
- Presence of overtaking opportunities

The research aims to determine how the presence or absence of the above geometrical factors may reduce road accidents.

## **3.5 Microsoft Excel analysis**

### **3.5.1 Quantification of results**

The main purpose of the Microsoft Excel analysis was to quantify the results obtained in the ArcGis analysis. This was done in the form of producing bar graphs, as well as producing tables to identify any significant patterns in the data. Quantification of the results would also assist in determining whether single vehicle overturning accidents had a higher frequency than other accident types.

## **3.6 Case Study**

### **3.6.1 Laingsburg-Beaufort West Case study**

The case study included a road safety audit of the study area. This was done after the geographical analysis, as the geographical analysis provided input for the Case Study. The road audit was performed through the method described in Chapter 2.8. The geometrical and infrastructural conditions of the N1 in the study area were analysed through a checklist which included infrastructure elements necessary along a highway.

A site visit was performed on the 21<sup>st</sup> of September 2013, which allowed for the Road Safety Audit to be conducted. The purpose of the road safety audit was also to evaluate the outputs obtained in the ArcGIs analysis.

### **3.6.2 City of Cape Town potential hotspot analysis**

The City of Cape Town data was also analysed geographically for potential hotspots during the years 2010 to 2013. Infrastructure conditions at fatal accident locations were also evaluated. The fatalities per month for the period 2010 to 2013 were also quantified through bar graphs, to show the trends in data for the four year period within the municipality. The purpose of this analysis was to determine whether the goals of the Safely Home campaign have been achieved by the PGWC.

### **3.7 Chapter summary**

This chapter presents the process followed in order to conduct the thesis. A literature review was done for the research proposal, as well as for the final thesis.

The flow chart indicates that the research design commenced with a desk study on black spot identification, road infrastructure and geometry, driving environment as well as data collection.

The data collection and analysis included analysis of PGWC data for single vehicle overturning accidents, as well as SANRAL data.

The geographical data was analysed using ArcGis 10.1 and the graphical representation of the findings done using Microsoft Excel. The factors considered during the analysis were mainly infrastructural and geometrical factors.

Thereafter, a case study of the Laingsburg-Beaufort West single vehicle overturning accidents was conducted, including a road safety audit to determine the infrastructural and geometrical factors that influence these accident types.

A secondary investigation of the City of Cape Town data was done, to determine the most prominent accident type and whether the Western Cape government has achieved its goals to reduce accidents by 50%.

## 4. Research findings

### 4.1 Introduction

This chapter aims to present the findings of the research. It focuses mainly on the results obtained from the PGWC 2007 data, a field investigation (case study) in which a road safety audit was conducted, as well as recent data provided by SANRAL of fatal accidents, which have occurred in areas close to the City of Cape Town Municipality. A discussion of these findings is presented in Chapter 5.

#### 4.1.1 Laingsburg-Beaufort West N1 hazardous location identification

A total of 130 fatal accidents occurred in the Laingsburg Beaufort West road section between the years 2000 to 2007.

Using the method suggested by Gitelman et al, (2012):

- 3 or more accidents over a 200m section

This would therefore require

- 3000 or more **fatal** accidents over a 200 kilometre road section.

Currently, the 130 accidents would not render the road section to be identified as a black spot. However, it should be taken into account that the frequency of accidents is currently relatively high and the term 'black spot' is used narrowly. The definition of a black spot should preferably be a location that has a **high frequency of accidents**, and not necessarily **fatal** accidents. The geographical data only has a record of fatal accidents, however, other accidents may have occurred, with no immediate fatalities or no fatalities at all. It is therefore important to have a record of all accident types, regardless of fatality occurrence.

This road section, however, has been pre-identified by the Provincial Government of the Western Cape as a black spot.

Figure 4.1 shows the different types of fatal accidents that occurred in the road section. It can be seen that single vehicle overturning accidents have a high incidence than all other accident types

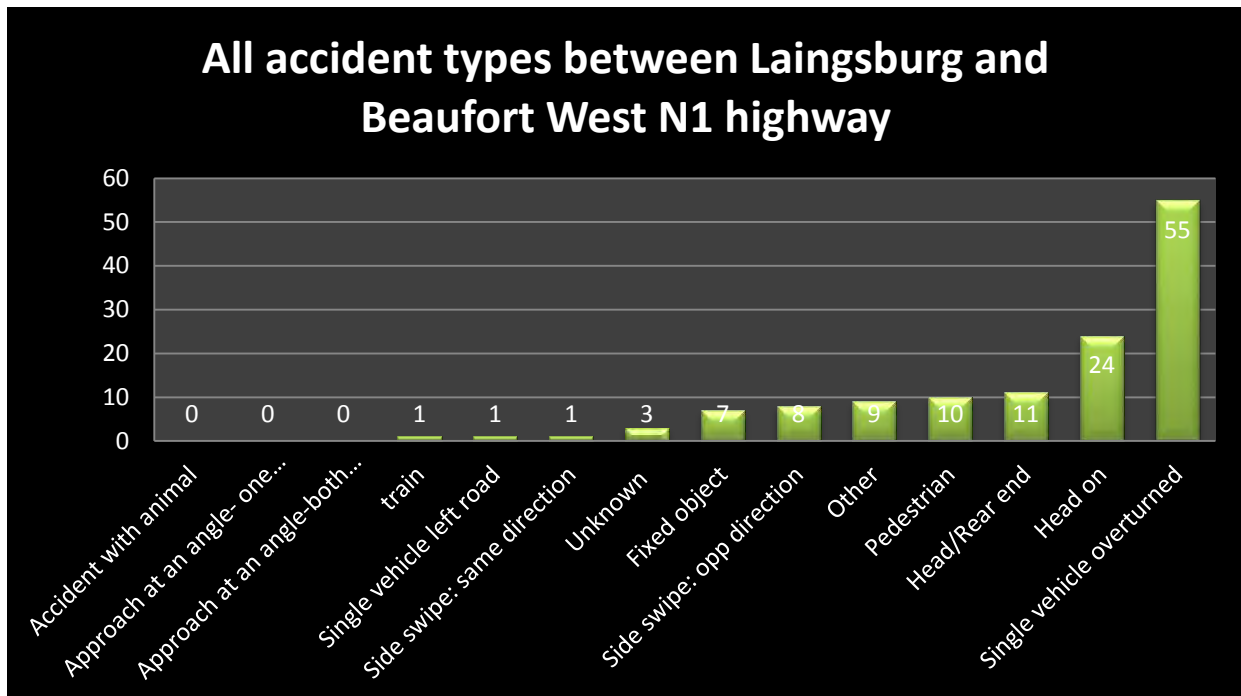


Figure 4.1: Laingsburg Beaufort West single-vehicle overturning accidents

Source: iPas

## 4.2 Study area

The study area is shown in Appendix B. Appendix B also shows the area in the Laingsburg municipality which is considered to be a hotspot. During the period 2000-2007, a total of 55 fatal accidents occurred on the N1 between Laingsburg and Beaufort West. As mentioned in Chapter 1, the study focused on the 55 single vehicle overturning accidents, which resulted in a total of 75 fatalities. The hazardous location analysed was a 200km stretch of road between Laingsburg and Beaufort West, and was mainly a single carriageway (undivided road).

The area circled in red shows the study area. Appendix B also shows that in the identified area, the accident types of interest are single vehicle overturning accidents along the N1.

Appendix C shows all the accident types within the study area during the 2000 to 2007 period.

## **4.3 Geographical Analysis of the data**

ArcGIS 10.1 was used to determine the hazardous locations. The geographical data obtained from the PGWC allowed for the identification of hazardous locations through clustering of accidents in a specific area. This clustering of accidents is also shown in Appendix C and thus the area can be identified as a hazardous location for accidents occurring between the 2000-2007 periods.

The geographical analysis also aimed to illustrate infrastructural deficiencies which govern single vehicle overturning accidents and this will be further discussed and illustrated in the following sections.

### **4.3.1 Road grade**

Appendix D is an ArcGIS generated map which shows the road grade in terms of its steepness. The area analysed is the hazardous location between Laingsburg and Beaufort West. ArcGIS was used to determine whether the road was either flat or on a gradient. The green dots show that the N1 stretch of road investigated was predominantly flat. The blue areas within this stretch of road indicate that the gradient of the road is unknown. This further shows the importance of road safety records and the disadvantages of missing data hindering road safety analysis of the road. Appendix D also shows that no parts of the road stretch were considered to be on a steep gradient (no blue spots within the road section).

### **4.3.2 Type of junction**

Appendix E shows the location of the accidents at time of occurrence with respect to the type of junction at which they occurred. The majority of the overturning accidents did not occur at junctions or intersections. Only one of the accidents occurred at a crossroads and one other at a junction type specified as 'other'. This is expected as the N1 is a straight highway with limited intersections.

### **4.3.3 Obstructions on road**

Appendix F was generated to determine if there were any obstructions on the road at the time of accident occurrence. The map shows that at the time of accident occurrence, there were no obstructions on the road in the form of roadblocks, road works and other obstructions which may lead to hazards

#### **4.3.4 Road markings**

Appendix G shows that road markings on this stretch of road between Laingsburg and Beaufort West are considered to be in 'Good' condition and thus cannot be a factor in the high accident rate of the hotspot.

Appendix H was generated to determine the presence of the road markings at the hazardous locations. The map also gives an indication of the types of road markings on the road which are important for overtaking opportunities. As depicted, there are a significant number of spots where the presence of road marking is indicated as 'unknown', as shown by the dark purple spots. The light green spots on the map show that a presence of a barrier line was noted in the road audit conducted during the 2000-2007 period. The red spots in the map show that there was no visible barrier line to motorists in that particular section of road. Although there are only a few spots with no barrier line, the safety of motorists is still compromised.

#### **4.3.5 Road signs**

Appendix I was generated to determine the condition of the road signs at the location of the fatal single vehicle overturning accidents. The map shows that the road signs on this section of the N1 are in good condition as shown by the light blue spots within the circle.

Appendix J was generated to determine whether road signs were present at the accident locations. The map shows that the entire road section is equipped with the proper road signage necessary for motorists to perform the driving task with ease and with the necessary precautions.

### **4.3.6 Road surface**

Appendix K is an ArcGIS generated map which shows the condition of the road surface at the hazardous locations. At the time of accident occurrence, the road surface was predominantly dry with only one single vehicle accident occurring in wet surface conditions.

Appendix L shows the type of road defects that were on the hazardous locations. The map also shows that the road surface was good at the time of accident occurrences, with no potholes or bumpy road surfaces, which may trigger or exacerbate accidents.

Appendix M was generated to show the type of material used to construct the road surface. The map shows that the road surface at the time of accident occurrence was made up of tarmac, with only one accident recorded as occurring on a concrete surface and one accident which occurred on a surface indicated as 'other'

### **4.3.7 Built up area**

Appendix N was generated to determine whether the accidents occurred near built up land uses. The map shows the distribution of accidents with regards to the nature of the surroundings adjacent to the accidents spots. Almost three quarters of the accidents occurred in areas that are adjacent to built-up areas, as indicated by the pink spots on the map. It can thus be said that the likelihood of accidents increases in built up areas near plain regions, as the Central Karoo is a plain desert region..

## 4.4 Graphical representation of the fatal accident data

This section aims to provide a graphical representation of all the accident fatality data associated with the Laingsburg Municipality. The accident data investigated showed that a total of 55 accidents occurred in the N1 section under the Laingsburg Municipality

### 4.4.1 Road type

Figure 4.2 shows the different road types that are encountered on the hazardous locations. It also quantifies the data, showing how many accidents occurred on the different road types.

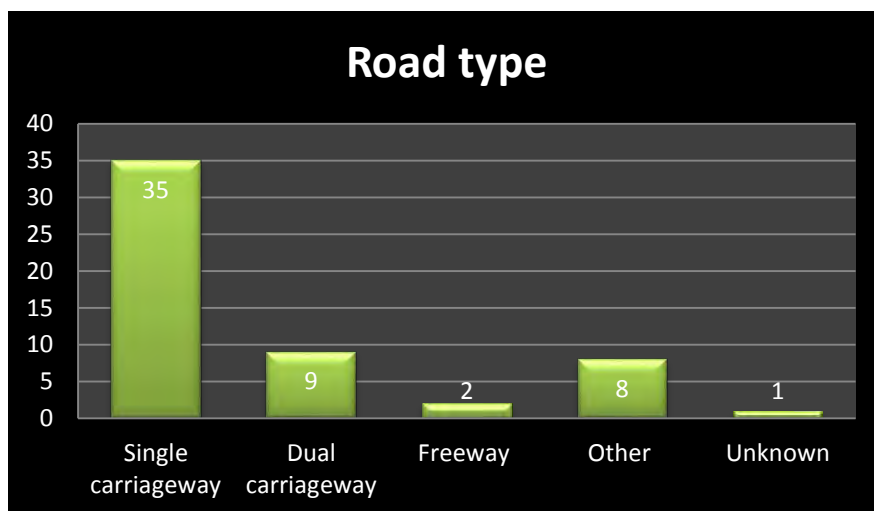


Figure 4.2: Type of road at accident spots

Source: iPas

The fatal accidents were found to have occurred on different road types. Some 35 accidents were found to have occurred on a single-carriageway, 9 occurred on a dual-carriageway, 2 occurred on a freeway, and 8 occurred on an 'other' type of road. Only 1 accident was found to have an unknown road type.

## 4.4.2 Built up area

Figure 4.3 shows the number of fatal single vehicle overturning accidents which occurred on built-up and non-built up adjacent land uses.

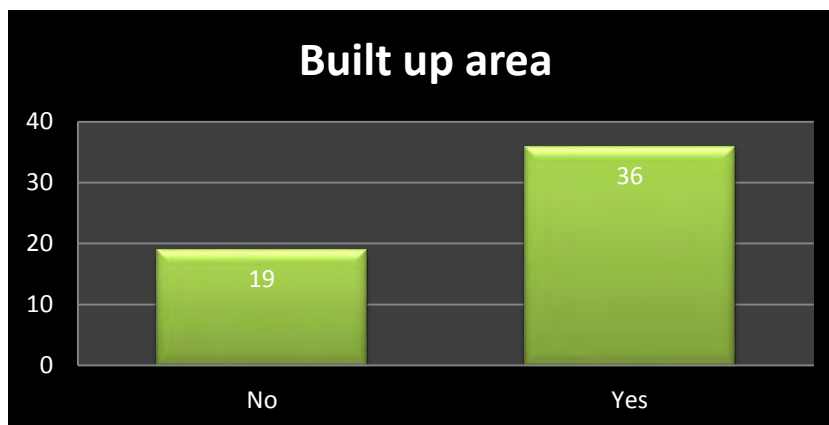


Figure 4.3: Graph showing number of built up land uses near accident hotspots

Source: iPas

Figure 4.3 shows the number of accidents that occurred near adjacent built up areas. The built environment is necessary in determining how conducive the road environment is to the driving experience. Of the 55 accidents investigated, 36 were confirmed to have occurred near a built up area, and 19 did not occur near a built up area.

Table 4-1: Carriageway type and built up land uses

Carriageway	Built up area		
	Yes	No	
Single	16	19	35
Dual	9		9
Freeway	2		2
Other	8		8
Unknown	1		1
	36	19	55

Table 4.1 depicts the relationship between carriageway type and built-up area adjacent land uses. As can be seen, 19 accidents occurred on a single-carriageway with no built up adjacent land uses, and 16 accidents occurred in areas with built up land uses. Some 9 accidents occurred on a dual carriageway, 2 on a freeway and 8 on 'other' type of carriageway and one unknown and all accidents on these road types occurred near built up adjacent land uses.

### 4.4.3 Road grade

Figure 4.4 shows the number of single vehicle overturning accidents which occurred on a flat or uphill road grade.

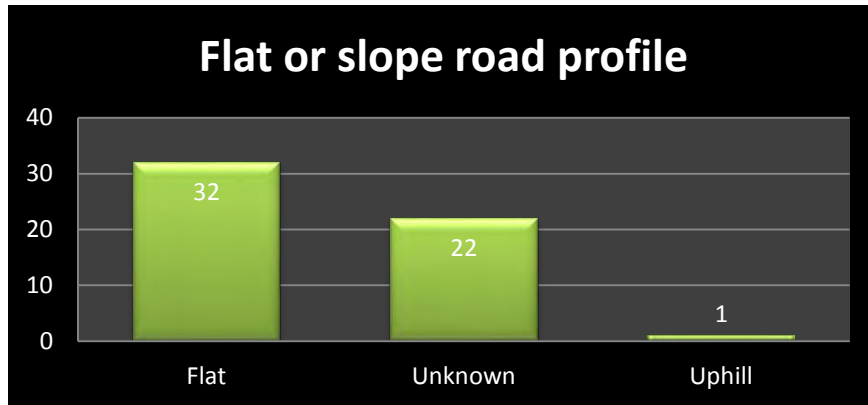


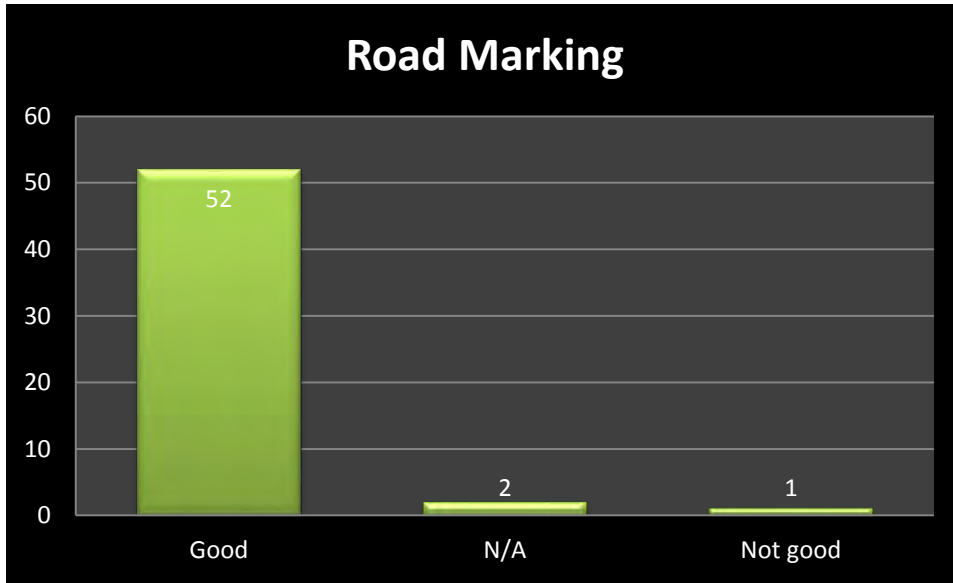
Figure 4.4: Numerical analysis of road profile at accident spots

Source: iPas

The super-elevation of the road is important as it relates to the road geometry. The gradient of the road should be appropriate for the driving task to be performed. Figure 4.4 shows that 32 accidents occurred on a flat road profile and 1 accident occurred on an uphill road surface. There were 22 incidents that were unknown, which infers missing data.

### 4.4.4 Road marking

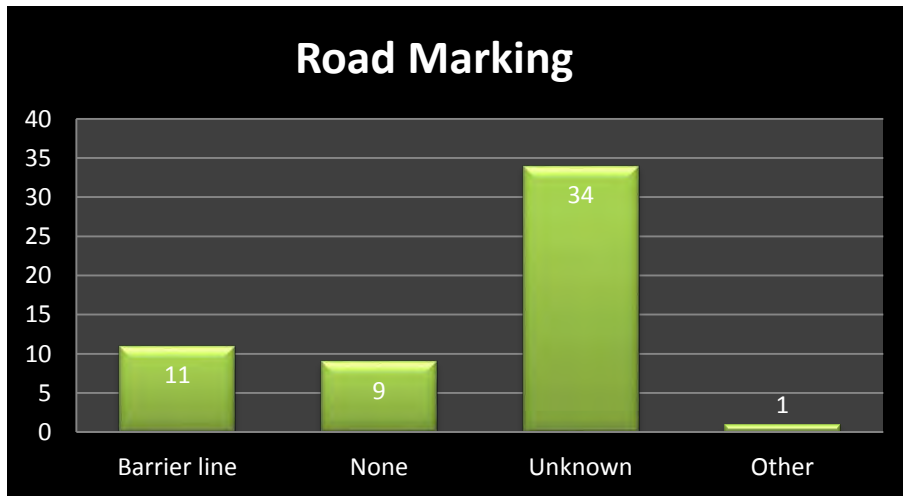
Figures 4.5 and Figure 4.6 show the number of single vehicle overturning accidents that occurred in areas where the road marking was good, and the type of road markings that were available in the hazardous locations.



**Figure 4.5: Condition of road marking**

*Source: iPas*

Figure 4.5 shows that the road markings were found to be in good condition when 52 of the accidents occurred. Only 1 incident was recorded as the road marking being ‘Not Good’



**Figure 4.6: Numerical analysis of type of road markings at accident location**

*Source: iPas*

Upon further investigation of the accident data, 11 accidents occurred when there was a visible barrier line, 9 occurred in conditions when there was no barrier line and 1 accident site had road markings recorded as ‘other’. For 34 accidents, the road markings were unknown, however, it can be deduced from Figure 4.5 that they were at least in good condition.

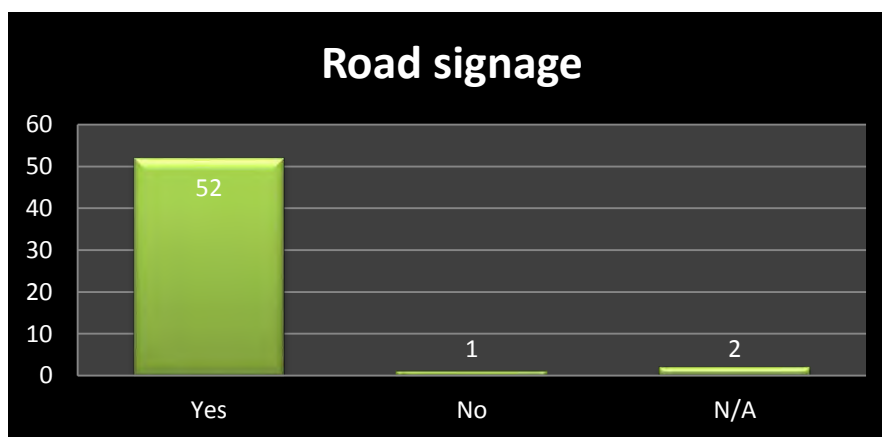
**Table 4-2: Condition and type of road markings**

	Road Markings			
	Good	Not Good	N/A	
Barrier line	11			11
None	7		2	9
Unknown	32	1	1	34
Other	1			1
	51	1	3	55

Table 4.2 depicts the relationship between the condition of the road markings, and the presence of the road markings. As can be seen above, 32 accidents occurred in an areas where the road marking was good, although unknown. Some 11 accidents occurred where there was a good barrier line. Some 7 accidents occurred in areas where the road markings were recorded as good, although there were no road markings.

#### 4.4.5 Road signage

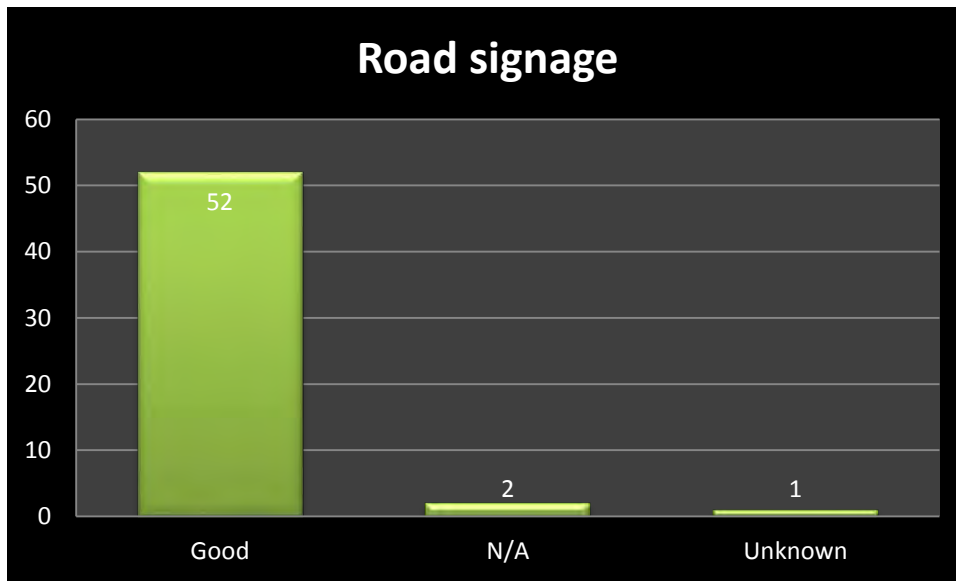
The number of accidents which occurred in areas where there was a presence of road signs and the condition of these road signs is depicted in Figures 4.7 and 4.8 respectively.



**Figure 4.7: Graphical representation of the presence of road signs at time of accident**

*Source: iPas*

Some 52 fatal accidents were found to have occurred with proper road signage in place, and only one accident was found to have occurred in an area with no road signs.



**Figure 4.8: Condition of road signs at accident locations** *Source: iPas*

In the sections where the accidents occurred, 52 of the accidents had good road signs, and 1 accident site had an ‘unknown’ road sign quality.

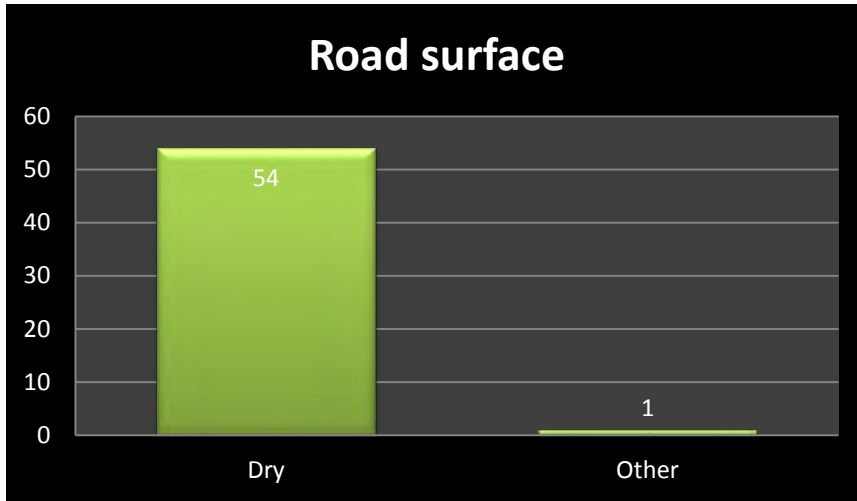
**Table 4-3: Condition and presence of road signs**

	Road signs			
	Yes	No	N/A	
Good	51	1		52
N/A			2	2
Unknown	1			1
	52	1	2	55

Table 4.3 shows the condition of road signs relative to their presence at the accident locations. Some 51 accidents occurred in locations where there was a presence of road signs, and which were in good condition. Only one accident occurred in a location where there was no road sign, although the condition of the road sign was recorded as being good.

#### **4.4.6 Road surface**

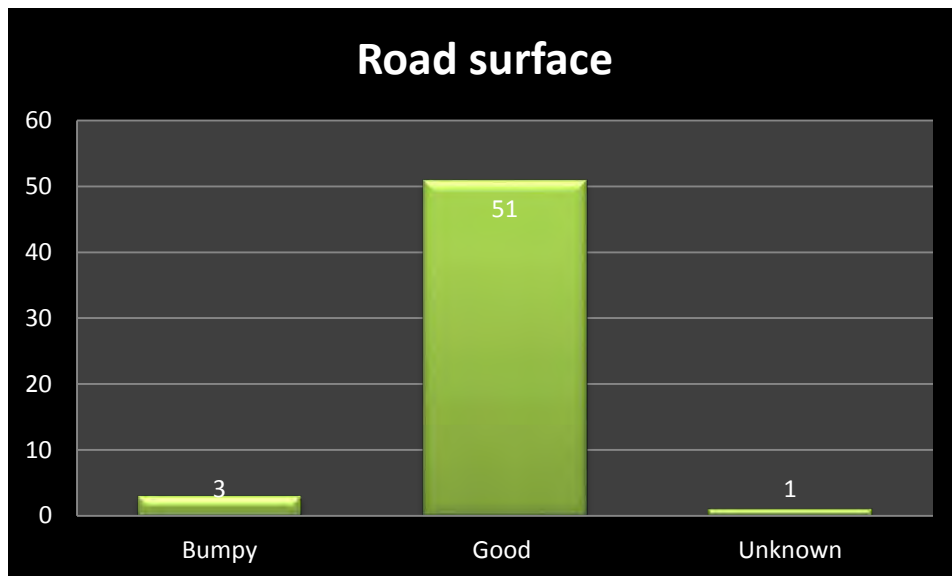
The condition of the road surface and material used to construct the road surface, may affect the frequency of accidents. Figures 4.9 to Figure 4.11 show the number of accidents that occurred on the different road surfaces.



**Figure 4.9: Condition of road surface at time of accident occurrence**

*Source: iPas*

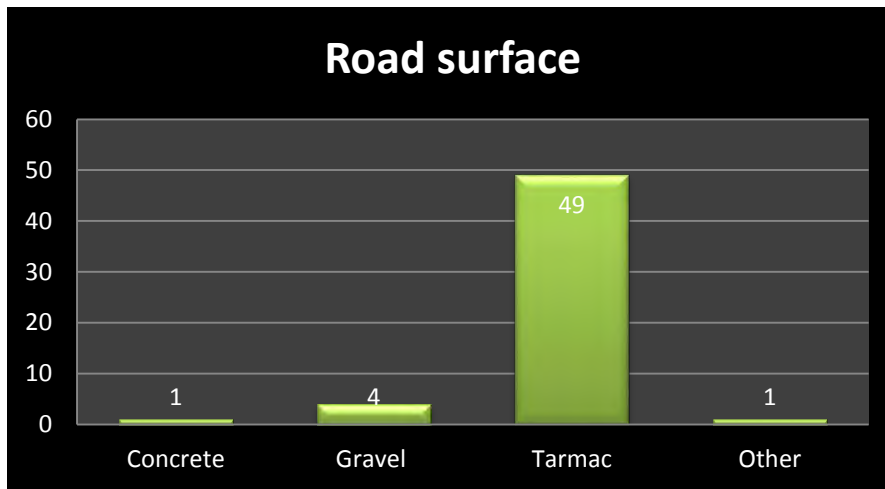
Figure 4.9 shows that in 54 of the 55 accidents, the road surface was dry.



**Figure 4.10: Road surface condition at accident location**

*Source: iPas*

Figure 4.10 shows that 51 accidents occurred on a good road surface. A total of 3 accidents occurred on a bumpy road surface and for 1 accident the road surface quality was recorded as unknown.



**Figure 4.11: Road surface type at accident location**

*Source: iPas*

Figure 4.11 depicts that 49 fatal accidents occurred on a tarmac surface, 4 occurred on a gravel road, and 1 accident occurred on a concrete road surface.

**Table 4-4: Condition of road surface and road surface material**

	Road surface				
	Concrete	Gravel	Tarmac	Other	
Bumpy		3			3
Good	1	1	49		51
Unknown				1	1
	1	4	49	1	55

Table 4.4 depicts the relationship between the road surface, and the type of material used to construct the road surface. As can be seen, 49 fatal accidents occurred on tarmac, and in locations where the road surface was good. Also, 3 accidents occurred on bumpy road surfaces, where the road was constructed using gravel material.

#### 4.4.7 Junction type

Figure 4.23 depicts the number of fatal single vehicle accidents that occurred on the different junction types.

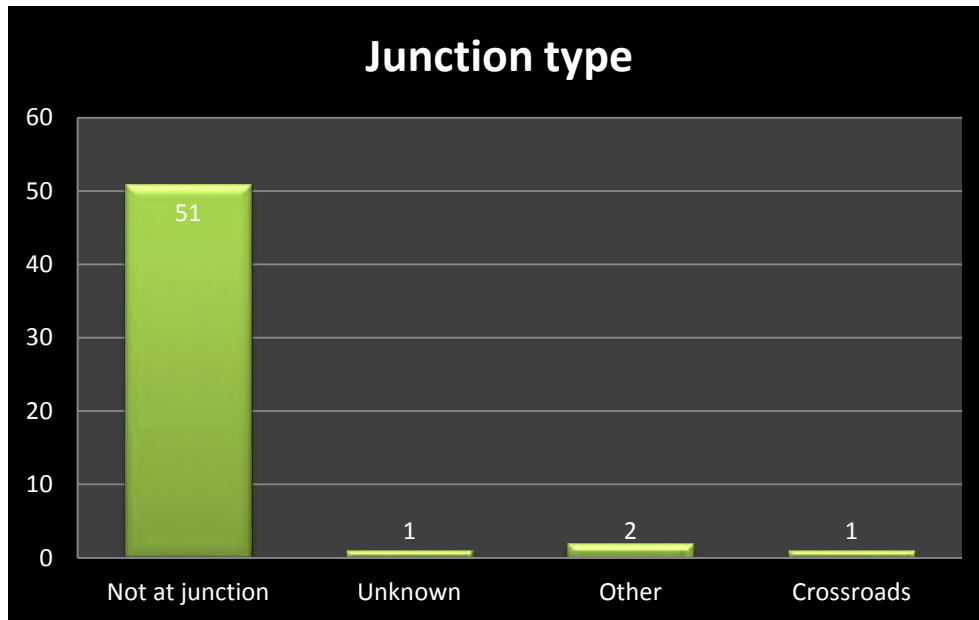


Figure 4.12: Junction type at location of fatal accident

Source: iPas

Figure 4.12 shows the type of junctions where accidents occurred. As can be seen, 51 of the 55 accidents did not occur at junctions along the N1. Only one accident occurred at a crossroads. A total of 2 accidents occurred at a location observed as 'other' and 1 accident location is unknown.

### 4.5 Summary of Laingsburg Accidents

Figure 4.13 gives an overview of the single vehicle accidents statistics for the Laingsburg area for the period 2000-2007. During the period investigated, **75** fatalities were recorded. Only 14 people were not injured, 189 people slightly injured and 43 people seriously injured. A total of 6 pedestrians were involved in the recorded accidents and **56** vehicles were involved altogether in the single vehicle overturning accidents during the period of investigation.

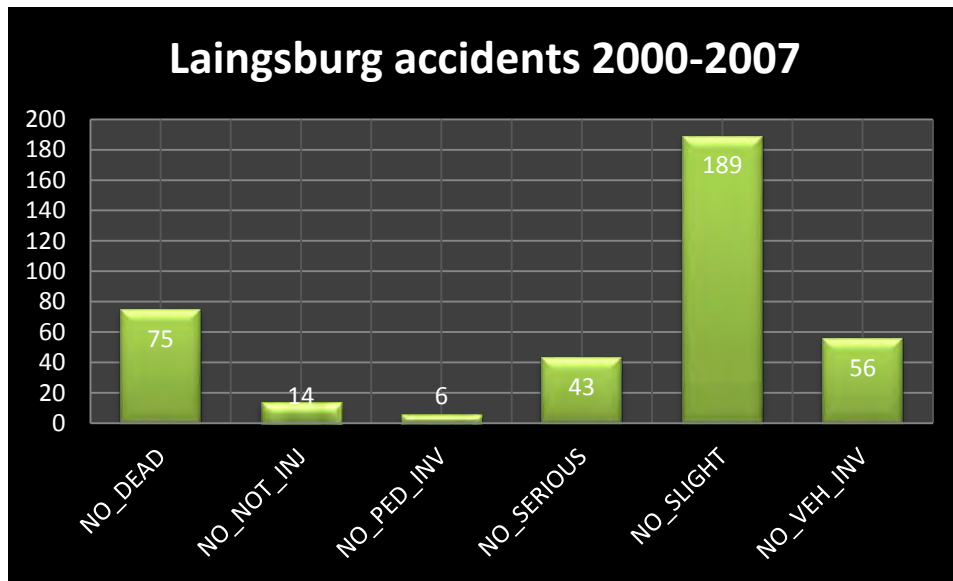


Figure 4.13: Summary of statistics for single vehicle overturning accidents

Source: iPas

## **4.6 Case Study: Laingsburg Beaufort West N1 highway Road Safety Audit**

### **4.6.1 Introduction**

This chapter presents the Road Safety Audit findings of the highway between Laingsburg and Beaufort West. Owing to the findings of the geographical analysis, it was important to conduct a road safety audit of the route under investigation. The road section is 200 kilometres in length. The audit findings were recorded every 10 kilometre of road section. Owing to the fact that the geographical data is for the years 2000 to 2007, it was imperative to perform an audit to determine:

- Current infrastructure conditions of the road
- To identify whether there have been any significant changes in infrastructure and operating elements between the years 2000 to 2007.
- To obtain a correlation between the 2000 and 2007 data by comparing the geographical findings to the road audit findings.
- To analyse the geometric conditions of the N1 between Laingsburg and Beaufort West, for a suitable driving environment.

The analysis criteria for the checklist relate mostly to the infrastructure, road geometry, road marking, road signing as well as road surfacing conditions along the N1 highway. The results of the checklist are summarised in Table 4.5 to Table 4.10. The results from the case study form an important aspect of the research, as a comparison can be done between the road safety audit findings and the geographical analysis findings for the years 2000 to 2007.

The road audit was performed according to the specifications and criteria listed in Chapter 2.8 by Cafiso et al. (2005) and potential highway problems, as observed by Bhatiti et al. (2010) were also to be observed in the road safety audit.

A summary of the features observed during the road safety audit are shown in Appendix O.

## 4.6.2 Road surface bleeding

Figure 4.14 shows the frequency of observations which had road surface bleeding on the N1 between Laingsburg and Beaufort West.

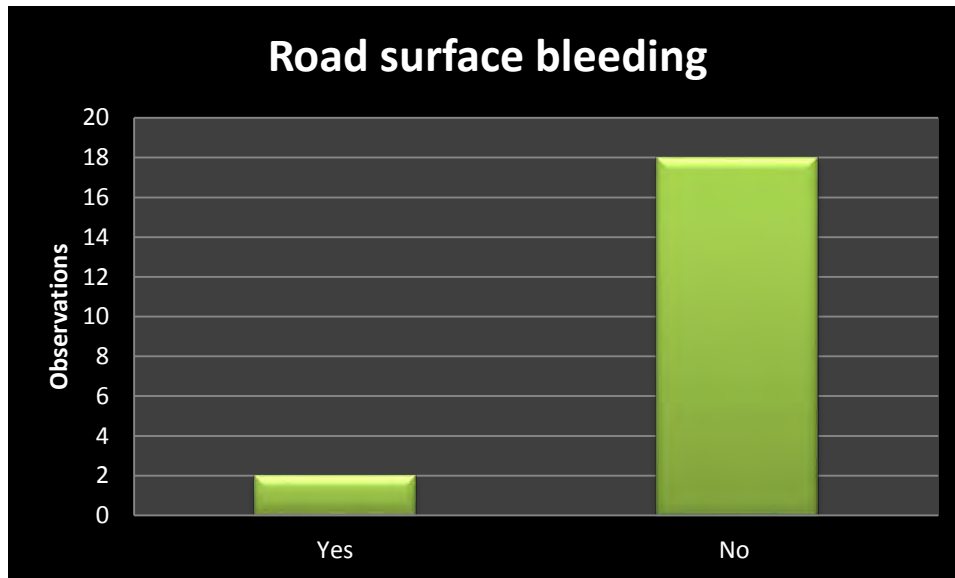


Figure 4.14: Road surface bleeding on highway

According to Figure 4.14, two observations were made where there was a presence of road surface bleeding. This was at 10-20 kilometres, and 110-120 kilometres.

Road surface bleeding would compromise motorists and results in skidding of vehicles in harsh weather conditions. At the time of investigation, road repairs were underway. These are usually done to make sure that the surface is free from any potholes, grooves and rutting, which was not observed during the investigation. There were no deformations observed on the road surface.

### 4.6.3 Visibility of road markings

Figure 4.15 shows the observations which had visible road markings

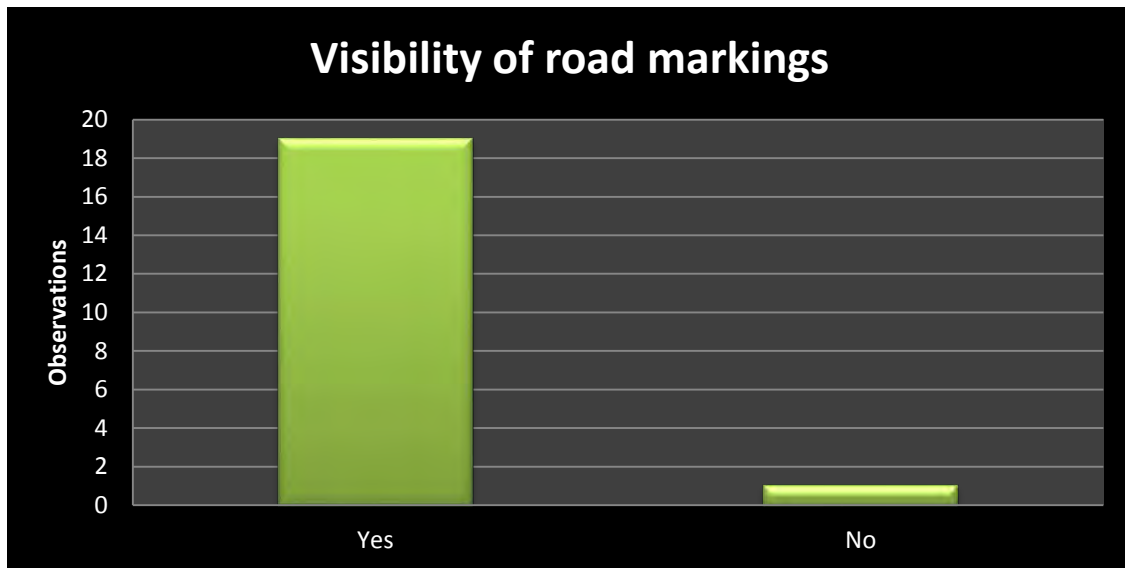


Figure 4.15: Visibility of road markings on highway

Figure 4.15 shows that there was a visible and clear presence of road markings at 19 of the 20 observations. Obscure road markings were visible at only 1 of the 20 stretches observed between Laingsburg and Beaufort West.

### 4.6.4 Road shoulder type

Figure 4.16 shows the road shoulder types on the N1.

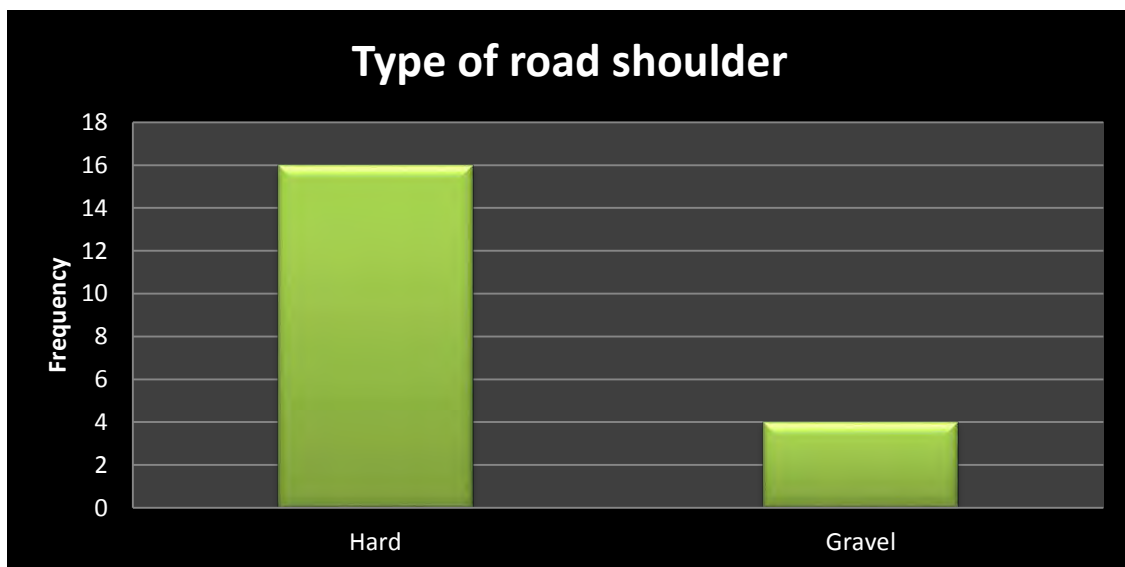


Figure 4.16: Road shoulder types on highway

Figure 4.16 shows that the type of road shoulders found on the N1 highway were hard shoulders, which were present in 16 of the 10 kilometre stretches. Gravel shoulders were present in four of the 10 kilometres stretches. Table 4.5 and Table 4.8 show that gravel shoulders which were present between 10-20 km; 50-60 km; 80-90 km; and 110-120 km.

#### 4.6.5 Average width of road shoulders

Figure 4.17 shows the width of edge road shoulders on the highway.

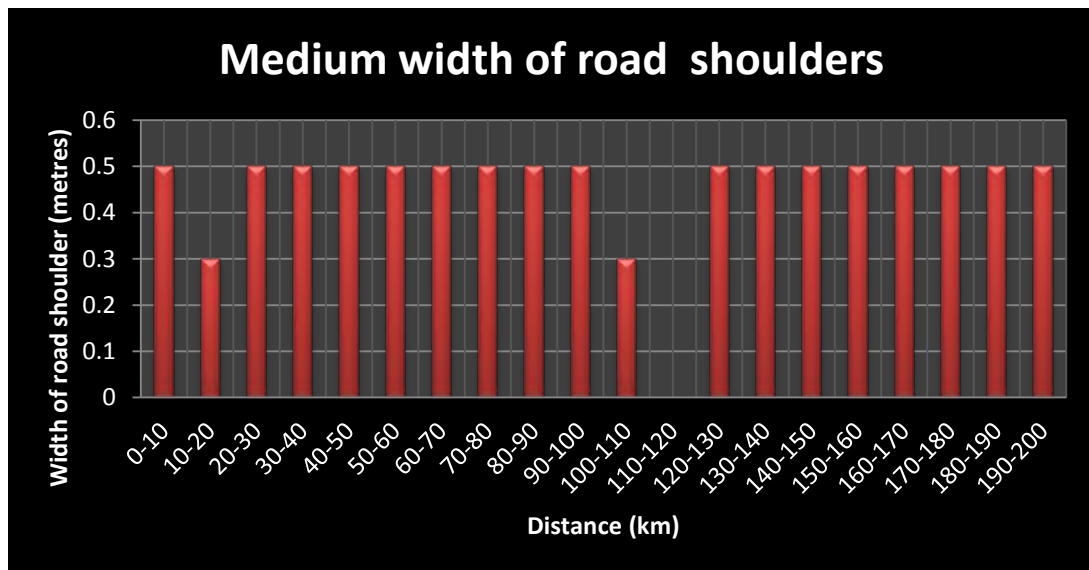


Figure 4.17: Average width of road shoulder on the highway

Figure 4.17 shows that the average width of road shoulders was 0.5 metres. At section 110-120 kilometres, there was no road shoulder outside the yellow line. The width of the road shoulder was 0.3 metres between 10-20 km and 100-110 km.

#### 4.6.6 Vegetation alongside highway

Figure 4.18 shows the frequency of vegetation observations along the N1.

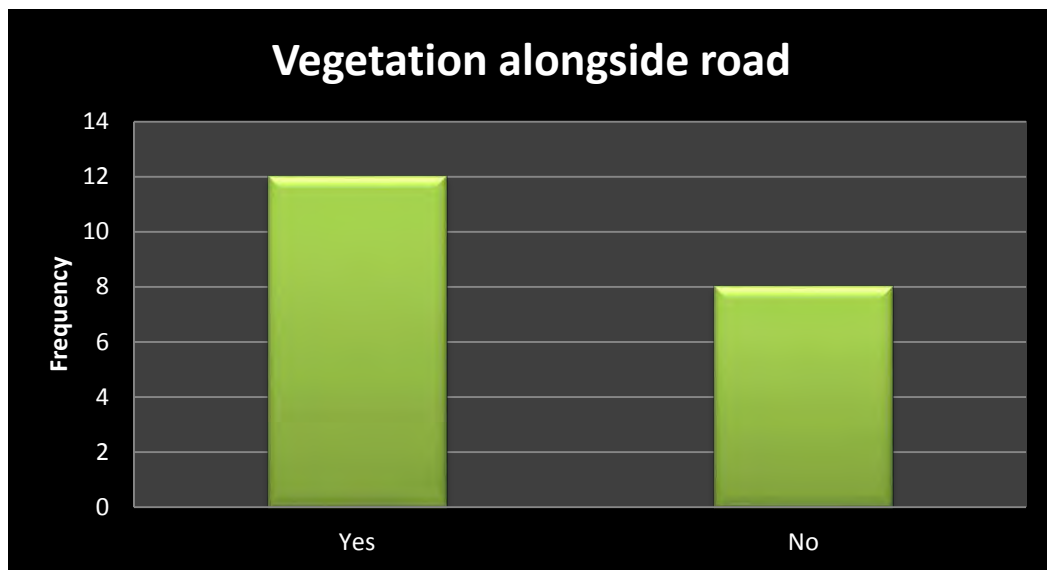


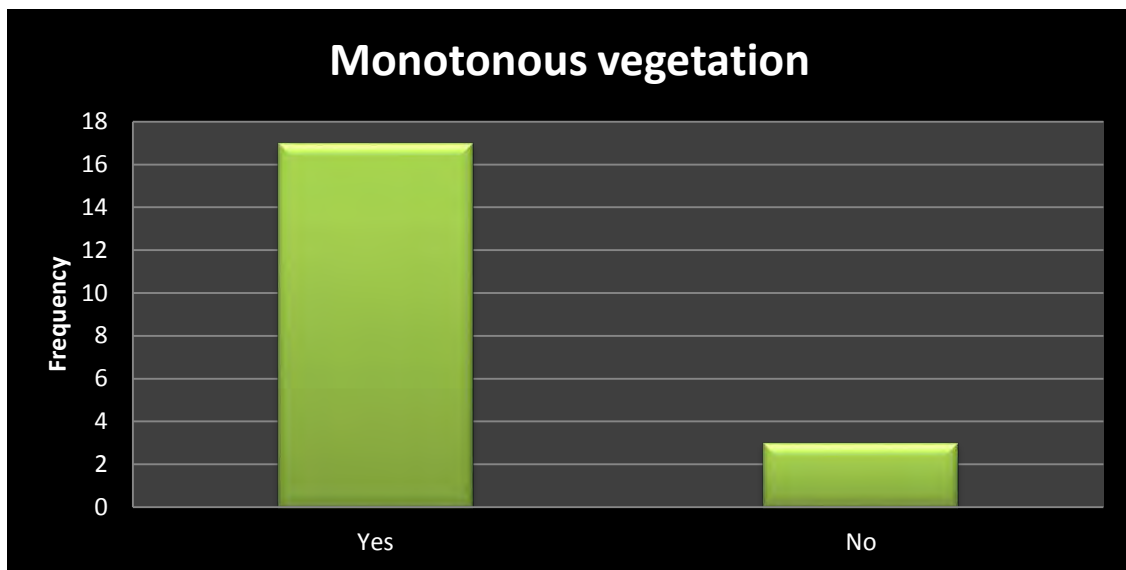
Figure 4.18: Vegetation along the highway

Visible vegetation on the road comprised mainly of cactus plants, which is consistent with a dry desert environment.

The vegetation could be said to be old and unlikely to protect the road or motorists from any disasters or floods that may occur. This is also revealed in Table 4.7 and 4.10.

#### 4.6.7 Monotonous vegetation

Figure 4.19 describes the frequency of observed monotonous vegetation.



**Figure 4.19: Monotonous vegetation along highway**

Observations on the presence of vegetation were made for every 10 km road section. There were no visible scars on any nearby trees or signposts that indicated that the area was a hotspot for accidents.

#### 4.6.8 Presence of guardrails

Figure 4.20 describes the observations which had adequate guardrail presence on the highway.

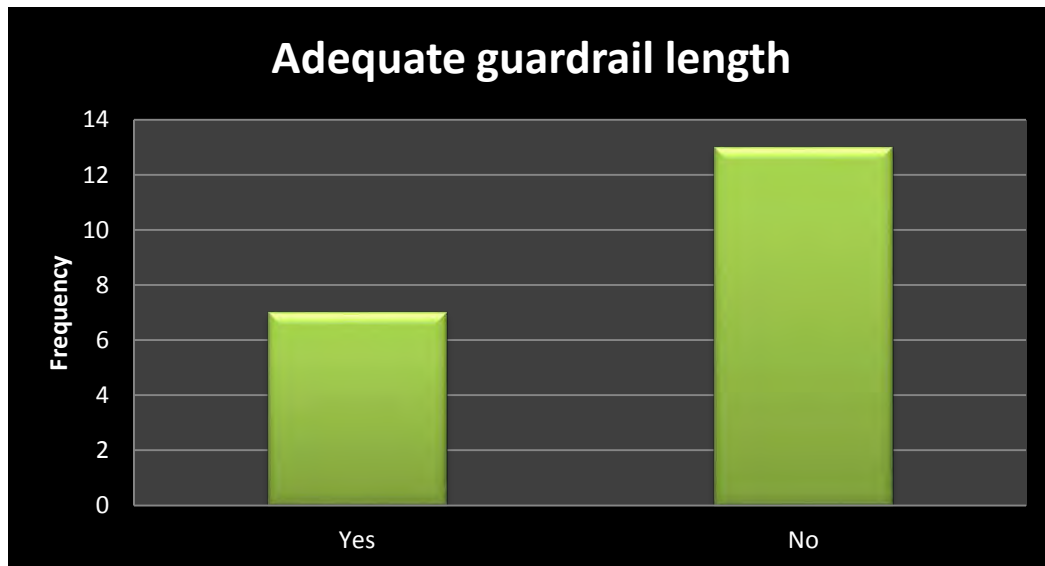


Figure 4.20: Adequacy of guardrail length on highway

Figure 4.20 shows that there were 13 observations where the guardrail length was considered inadequate.

#### 4.6.9 Presence of drainage system

Figure 4.21 shows the number of observations which had drainage infrastructure.

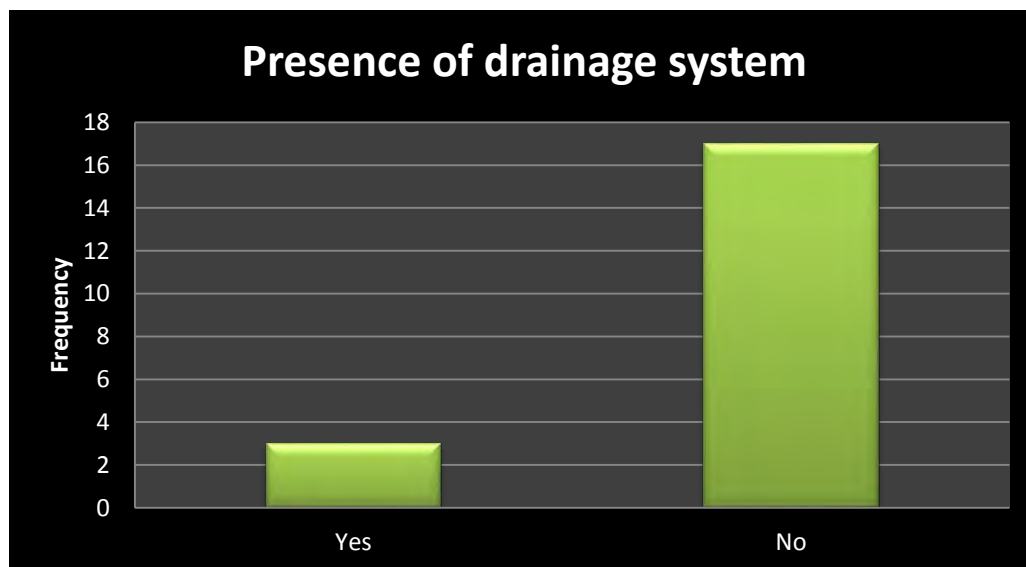


Figure 4.21: Presence of drainage system

Figure 4.21 shows that 3 observations were made where there was a presence of a drainage system. Drainage systems were located at 0-10 kilometres; 110-120 kilometres and 190-200 kilometres.

The cambering of the road, which is designed for road drainage purposes, is considered to be constant throughout the straight sections of the route investigated, which is the entire highway. This is also illustrated in Table 4.5 and Table 4.8.

#### 4.6.10 Perpendicular intersections present on the highway

Figure 4.22 shows the number of observations in which an intersection was observed.

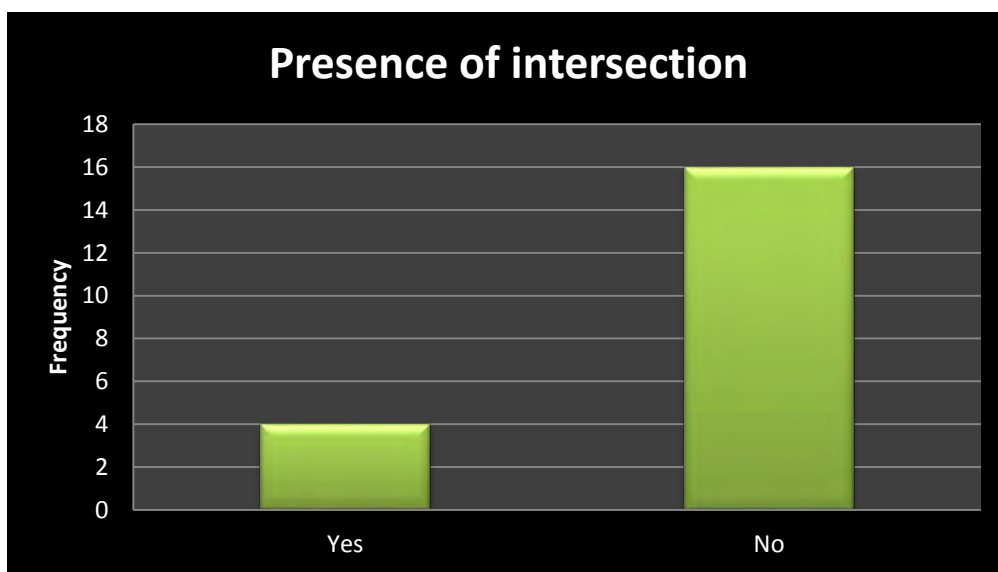


Figure 4.22: Presence of intersections on highway

According to Figure 4.22, there were four observations where there was a presence of an at grade intersection, this was at 10-20 kilometres, 110-120 kilometres and 120-130 kilometres.

### 4.6.11 Built up area

Figure 4.23 shows the numbers of observations of built up areas.

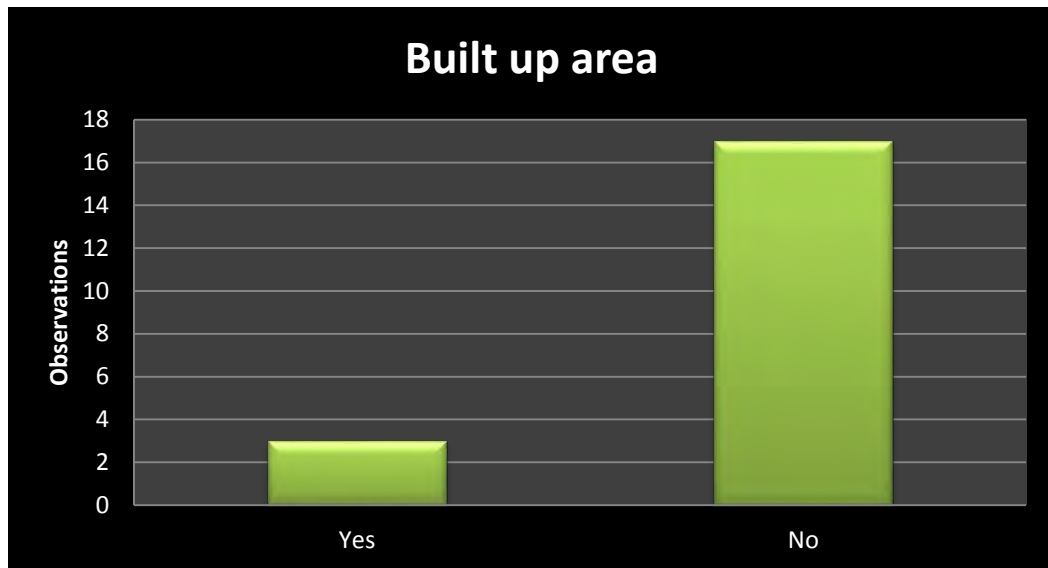


Figure 4.23: Built up areas located on the highway

Figure 4.23 shows that there were 3 observation were built up areas. These were between 20-30 kilometres, 100-110 kilometres and 110-120 kilometres.

### 4.6.12 Street-lighting on highway

Figure 4.24 shows the number of observations in which streetlamps were observed on the N1.

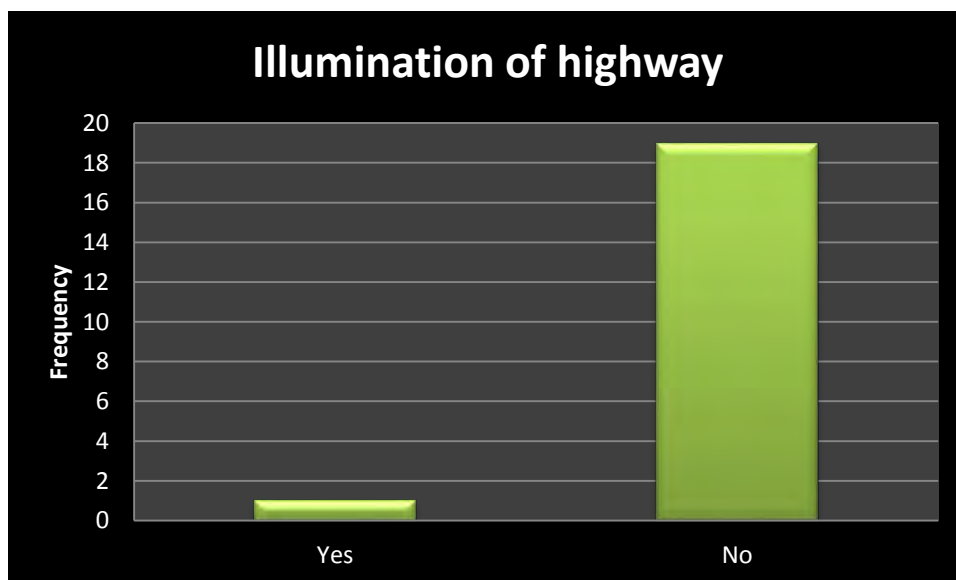


Figure 4.24: Illumination presence on highway

The route was poorly illuminated as street lights were not present throughout the highway. This is illustrated in Figure 4.24, as there was one observation, between 0-10kilometres, were

there was a presence of streetlights. They were only detectable in town, although not entirely helpful in detecting pedestrians within the roadway.

#### **4.6.13 Cross-section**

Table 4.5 and Table 4.8 reveal that there were no locations where there were small radii with wide pavements. Figure 5.4 reveals that the width of the road shoulder was constant throughout the highway at 0.5 metres.

Due to the fact that the carriageway was a single carriageway, no narrowing to increase traffic safety is required, but rather widening of the carriageway, to increase over-taking opportunities would be beneficial.

#### **4.6.14 Alignment**

The existing speed limit of the highway is 120 km/hour. This speed limit was thought to be adequate for the horizontal and vertical elements of the alignment.

Table 4.5 and Table 4.8 also shows that the line of sight for the driver was not obstructed by safety barriers such as fences, road equipment, parking areas, traffic signs, landscaping, bridges and buildings in the vicinity of the site. Motorists were made aware of any possible hazards due to road repairs on the road in advance of approaching these sections.

The route did not have any sharp curves, hence visibility was ensured at all times. However, overtaking opportunities in this route were observed to be insufficient. The route is a single carriageway with very few overtaking opportunities, which lead to risk taking by motorists.

Optical illusions that may affect the driving experience were noted to be hot-road mirages, which are due to heated air above tarmac in hot weather conditions. These created an illusion of spilled water on the road.

#### **4.6.15 Service and rest areas**

The route is well-equipped with service and rest areas, along with parking facilities on both sides of the road. This is shown in Table 4.6 and Table 4.9. These rest areas are located every 10 kilometres of road travelled. However, the sizes of these areas do not include sufficient parking for trucks, buses and passenger vehicles. The parking and rest areas are also not separated according to vehicle type. These areas are clearly marked and demarcated from the carriageway, with delineators prominent across the rest areas.



**Figure 4.25: Rest area situated along the N1 hotspot outside Laingsburg**

*Source: Nasiphi Dinga 2013*

The location of these areas does not obstruct sight distance for road users of the road carriageway. This area can be considered to also provide access for rescue and maintenance vehicles.

#### **4.6.16 Road Signing**

Table 4.6 and Table 4.9 reveal that there was sufficient road signing on the highway. The highway was also equipped with reflectors for night visibility. The presence of road signs did not obstruct traffic and any other road signs. It was noted that there were no warning signs visible that prohibited overtaking on the route, even though there were very few overtaking opportunities and motorists were likely to take risks. The rest areas were clearly marked with appropriate road signs, which were also consistent throughout the route. There was a lack of greenery in the vicinity, which was unlikely to lead to future problems such as compromising road signs by covering them. The signs on the highway were readable from a distance to motorists, as they were at required heights to ensure visibility to the motorists. However, they were not located at safe distances above the carriageway, which has a minimum of 3 metres.

#### **4.6.17 Location of fixed objects**

Table 4.5 and Table 4.8 reveal that fixed objects were not located at distances greater than 9 metres relative to the highway. These objects pose as a hazard in case of vehicle skidding in inclement weather conditions. The requirement for a 100 km/hour safety zone, obstacles should be placed 9 metres from the road, in an 80km/hour zone, obstacles should be placed 6 metres away and for a 60 km/hour zone should be placed 3 metres away. The route inspected was considered to be a 120 km/hour speed zone; hence objects were to be located at 9 metres or more from the highway.

Table 4.5 to Table 4.10 present the research findings of the road audit. These findings will assist in determining whether a correlation exists between the road audit findings and the geographical analysis findings. They will also assist in determining whether further precautions need to be taken in order to improve the safety of the highway. Appendix O shows the location of the different findings of the road audit, and where potential hazards may occur due to insufficient infrastructure.

**Table 4-5: Summary of checklist showing Operating elements, cross-section, alignment and intersection of highway for distances 0-100 kilometres**

	Kilometres	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Function, operating elements and surroundings	Built up area	x	x	√	x	x	x	x	x	x	x
	SSD	√	√	√	√	√	√	√	√	√	√
	Fixed objects>9metres	x	x	x	x	x	x	x	x	x	x
Cross-section	Surface bleeding/potholes	x	√ gravel edge	x	x	x	x	x	x	x	x
	Hard or gravel shoulders	Hard camber	gravel edge camber	hard camber	hard camber	hard camber	gravel	hard camber	hard camber	gravel camber	hard camber
	Crossfall	x	x	x	x	x	x	x	x	x	x
	Median present	0.5	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Medium width of shoulders small radii with large pavement width	x	x	x	x	x	x	x	x	x	x
Alignment	Visibility obscured	x	x	x	x	x	x	x	x	x	x
	Overtaking possibilities	√	√	√	x	√	x	x	x	x	x
	Optical illusions	√	√	√	√	√	√	√	√	√	√
Intersections	Intersections perpendicular	√	x	-	-	x	x	-	-	√	x
	Clearly recognizable	x	-	-	-	-	-	-	-	x	-
	Sight obstructed	x	-	-	x	-	x	x	-	x	x
	Type and design suitable for function	√	√	√	√	-	√	√	-	x	-
	Speed limits obeyed	√	√	-	√	-	√	√	-	-	-

**Table 4-6: Summary of checklist showing Service areas, Traffic signing, Road Markings and Lighting for distances 0-100 kilometres**

Kilometres		0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Service and rest areas	Sufficient parking bays	√	√	√	√	√	√	√	√	√	√
	Parking separated from carriageway	√	√	√	√	√	√	√	√	√	√
	Illegal parking on carriageway avoided	√	√	√	√	√	√	√	√	√	√
Traffic signing	Appropriate speed limits	√		√	√	√			√	√	√
	Signing for rest areas clear	√	√	√	√	√	√	√	√	√	√
	Signing obstruct visibility			x	x	x		x	x	x	x
	Signs located where needed	√	√	√	√	√	√	√	√	√	√
Road marking	Road markings clearly recognizable	√	√	√	√	x	√	√	x	√	√
	Markings appropriate for function of road	√	√	√	√	√	√	√	x	√	√
	Markings visible under all expected conditions	√	√	√	√	x	√	√	x	√	√
Lighting	Road sufficiently illuminated	x	x	x	x	x	x	x	x	x	x
	Pedestrians visible	√	-	-	-	-	-	-	-	-	-
	Traffic signs and road alignment visible	√	x	x	x	x	x	x	x	x	x
	Stationary lighting at rest areas properly situated	x	x	x	x	x	x	x	x	x	x

**Table 4-7: Summary of checklist showing Plantings, Civil Engineering Structures, and other road equipment for distances 0-100 kilometres.**

	Kilometres	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Plantings	Vegetation along the road present	√	x	√	x	x	x	x	√	x	x
	Sight obstructed by trees or plants	√	x	x	x	x	x	x	x	x	x
	Vegetation monotonous	√	x	x	x	√	√	√	√	√	√
	Vegetation protect the road from natural disasters	√	√	√	√	√	√	√	√	√	√
Civil engineering structures	Drainage system present	√	x	x	x	x	x	x	x	x	x
	Adequate guardrail length	√	x	√	x	x	x	x	x	x	x
Other road equipment	Game fencing present	x	√	√	√	√	√	√	√	√	√

**Table 4-8: Summary of checklist showing Operating elements, cross-section, alignment and intersection of highway for distances 100 - 200 kilometres**

		100-110	110-120	120-130	130-140	140-150	150-160	160-170	170-180	180-190	190-200
Function, operating elements and surroundings	Built up area	√	√	x	x	x	x	x	x	x	x
	SSD	√	√	√	√	√	√	√	√	√	√
	Fixed objects>9metres	x	x	x	x	x	x	x	x	x	x
Cross-section	Surface bleedingpotholes	x	√	x	x	x	x	x	x	x	x
	Hard or gravel shoulders	hard	gravel	hard	hard	hard	hard	hard	hard	hard	h
	Crossfall	camber		camber	camber	camber	camber	camber	camber	camber	camber
	Median present	x		x	x	x	x	x	x	x	x
	Medium width of shoulders	0.3	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	small radii with large pavement width	x	x	x	x	x	x	x	x	x	x
Alignment	Visibility obscured	x	x	x	x	x	x	x	x	x	x
	Overtaking possibilities	x	x	x	x	x	x	x	x	x	x
	Optical illusions	√	√	√	√	√	√	√	√	√	√
Intersections	Intersections perpendicular	x	√	√	x	x	x	x	x	x	
	Clearly recognizable	-	x	x	-	-	-	-	-	-	√
	Sight obstructed	-	x	x	-	-	-	-	-	-	x
	Type and design suitable for function	-	x	x	-	-	-	-	-	-	√
	Speed limits obeyed	-	-	-	-	-	-	-	-	-	x

**Table 4-9: Summary of checklist showing Service areas, Traffic signing, Road Markings and Lighting for distances 100 - 200 kilometres**

	Kilometres	100-110	110-120	120-130	130-140	140-150	150-160	160-170	170-180	180-190	190-200
Service and rest areas	Sufficient parking bays	√	√	√	√	√	√	√	√	√	√
	Parking physically separated from carriageway	√	√	√	√	√	√	√	√	√	√
	Illegal parking on carriageway avoided	√	√	√	√	√	√	√	√	√	√
Traffic signing	Appropriate speed limits	√	√	√	√	√	√	√	√	√	x
	Signing for rest areas clear	√	√	√	√	√	√	√	√	√	√
	Signing obstruct visibility	x	x	x	x	x	x	x	x	x	x
	Signs located where needed	√	√	√	√	√	√	√	√	√	x
Road marking	Road markings clearly recognizable	√	√	√	√	√	√	√	√	√	√
	Markings appropriate for function of road	√	√	√	√	√	√	√	√	√	√
	Markings visible under all expected conditions	x	√	√	√	√	√	√	√	√	√
Lighting	Road sufficiently illuminated	x	x	x	x	x	x	x	x	x	x
	Pedestrians visible	-	-	-	-	-	-	-	-	-	-
	Traffic signs and road alignment visible	-	-	-	-	-	-	-	-	-	-
	Stationary lighting at rest areas properly situated	-	-	-	-	-	-	-	-	-	-

**Table 4-10: Summary of checklist showing Plantings, Civil Engineering Structures, and other road equipment for distances 100 - 200 kilometres.**

	Kilometres	100-110	110-120	120-130	130-140	140-150	150-160	160-170	170-180	180-190	190-200
Plantings	Vegetation along the road present	x	√	√	√	√	√	√	√	√	√
	Sight obstructed by trees or plants	x	x	x	x	x	x	x	x	x	x
	Vegetation monotonous	√	√	√	√	√	√	√	√	√	√
	Vegetation protect the road from natural disasters	√	√	√	√	√	√	√	√	√	√
Civil engineering structures	Drainage system present	x	√	x	x	x	x	x	x	x	√
	Adequate guardrail length	√	x	√	x	x	x	√	√	x	√
Other road equipment	Game fencing present	√	√	√	√	√	√	√	√	√	√

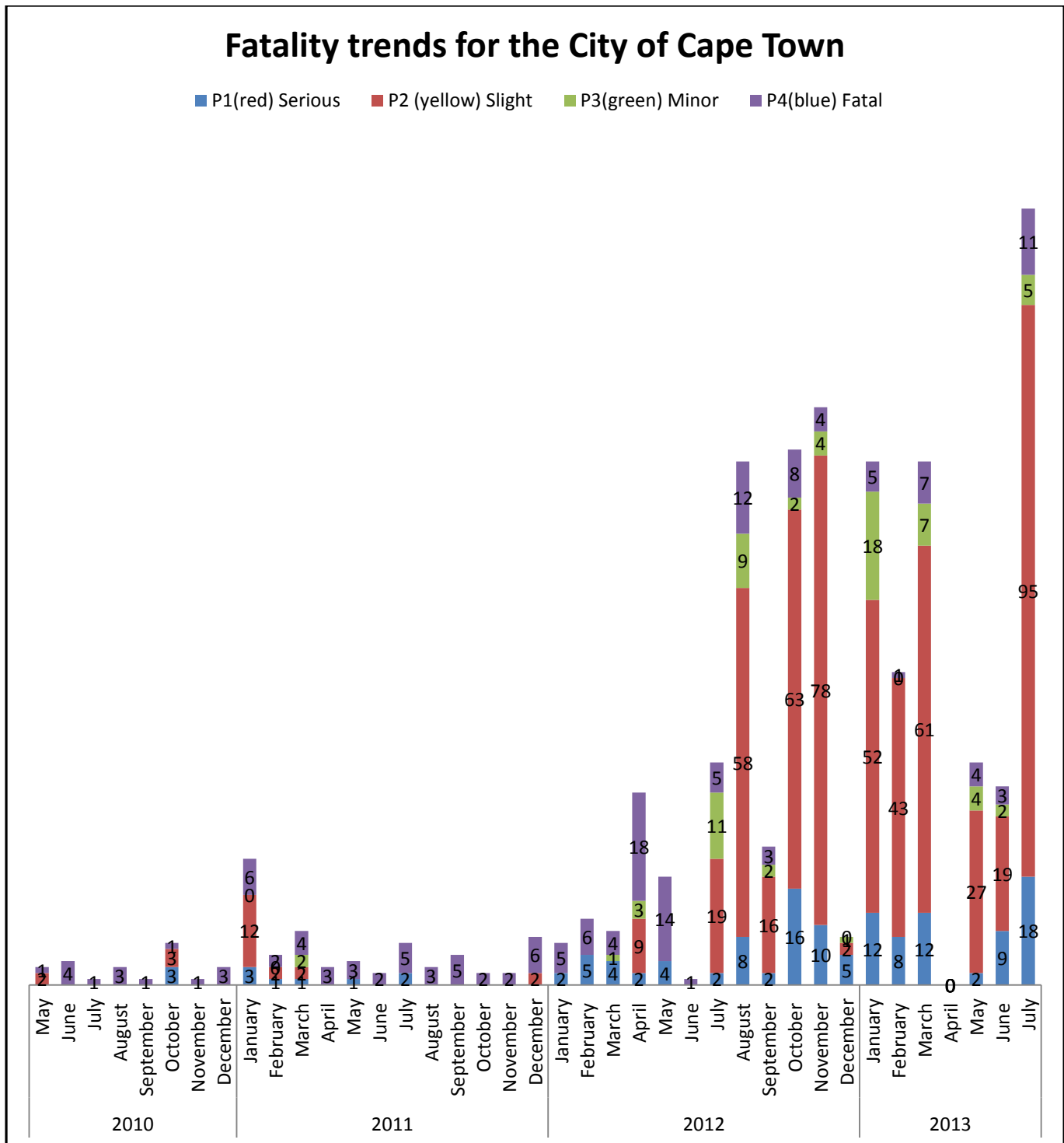
Legend	
Yes	√
No	x
Not applicable	-

## **4.7 Findings for City of Cape Town Municipality**

### **4.7.1 Introduction**

The geographical analysis was performed on data for the Western Cape region. This data was for the years 2000 to 2007. The Road Safety Audit was performed on the N1 section between Laingsburg and Beaufort West, which has a high incidence of single vehicle overturning accidents. The data from the PGWC did not have any information on accidents within the City of Cape Town municipality. Data from SANRAL was obtained, and investigated on whether there were any prevalent accident types, and how severe the fatalities were. It was part of the Provincial Government of the Western Cape's mandate to reduce accidents by 50% between the years, 2009 and 2014 ( END 5047Z notes, 2012).

Figure 4.26 shows the injury types present within the municipality for the years 2010 to 2013.



**Figure 4.26: City of Cape Town municipality accident data for the period June 2010 to July 2013** *Source: SANRAL*

Figure 4.26 above depicts the accident data for the period 2010 to July 2013. During the period June 2010-June 2012, a total of 112 fatal accidents were recorded, 28 serious injuries, 34 slight and 6 minor injuries were suffered by the victims. For the period July to December 2012, the worst fatalities were observed in the month of August with 12 fatalities, 8 serious injuries, 9 minor and 58 slightly injured victims. During the December period, which is

associated with the festive season, there were no fatalities recorded and 5 seriously injured people. However, January 2013 reflects significantly different statistics as there are 5 recorded fatalities, 12 serious injuries, 18 minor and 52 slightly injured victims.

The month of July recorded the worst fatalities to date, with 11 fatalities, 18 serious injuries, 5 minor, and 95 slightly injured victims.

Appendix P shows the location of fatalities within the City of Cape Town municipality for the period 2010 to 2013.

For the period May to December 2010: 14 fatalities were recorded.

2011 Period: 44 fatalities were recorded

2012 Period: 80 fatalities were recorded

January to July 2013: 13 fatalities were recorded

#### **4.7.2 Accident types within the City of Cape Town municipality**

Analysis of the city of Cape Town accident data revealed that the accident types were not recorded, therefore an analysis of any single vehicle overturning accidents could not be done along the N1 highway within the municipality. However, further analysis showed that pedestrian fatalities had a high incidence rate. Appendix Q shows the location of pedestrian accidents.

According to Gitelman et al., (2010), a location with 3 or more pedestrian fatalities within a 3 year period can be identified as a black spot. This leads to the identification of the Khayelitsha area (outside N1 study area) as a black spot as indicated by the number of pedestrian fatalities in Appendix Q.

### **4.8 Chapter Summary**

This chapter presents the research findings for the geographical analysis performed on the PGWC data, as well as the Road Safety Audit performed on the Laingsburg Beaufort West study area. Further findings are presented on data obtained from SANRAL.

Findings of the geographical analysis revealed that single vehicle overturning accidents had a high incident rate in the study area. The study area, Laingsburg-Beaufort West, was also revealed to be predominantly a single carriageway throughout the N1 section. This factor is

closely related to the road geometry, and overtaking opportunities available on the road section.

The geographical analysis also revealed that majority of the fatal accidents occurred near built up land uses. Built up areas are important as they provide a variable road environment.

The N1 section was also a flat road surface, with no accident occurring on uphill road sections.

Road markings, which form part of the road infrastructure, were revealed to be in good condition and barrier lines were visible at time of accident occurrence. Road signs were also present at accident locations and were in good condition. The road surface was made of tarmac with no potholes and other defects at the accident locations.

The geographical analysis also revealed that no accidents happened at junctions and that there were no obstructions on the road at the time of accident occurrence.

The road safety audit revealed that the road infrastructure, which includes road markings, road signs were in good condition. However, road signs were located at distances too close to the highway.

The road surface was also in good condition, although there was some road surface bleeding observed at certain locations. Gravel shoulders were also observed at specific sections of the highway.

Part of the road infrastructure includes guardrails, which assist in preventing vehicles from veering off the road surface. These were found to be lacking on the highway, with few highway sections having adequate guardrail length.

The road environment, which includes vegetation and built up land uses, was revealed to be monotonous. There were a small number of road sections with built up land uses, and the vegetation was not variable. There was also insufficient illumination along the highway, hence visibility was compromised especially at night. Factors such as stopping sight distance, which form an important part of the road geometry, were considered sufficient. Overtaking opportunities are limited, which may result in risky driver behaviour.

The analysis of the City of Cape Town data revealed the injury types and fatalities from the years 2010 to 2013. However, this data only showed pedestrian accidents and no other

accident types. Pedestrian accidents may warrant pedestrian infrastructure (pedestrian bridges, walkways) in locations where there are conflicts between pedestrians and vehicle movements.

## **5. Discussion of results**

### **5.1 Introduction**

This chapter aims to discuss the findings of the research investigations. This includes the findings of the geographical analysis, as well as the results of the road audit. The results of the City of Cape Town hazardous location analysis are also discussed.

The main sections discussed include the road grade, which can either be flat or uphill. The presence and type of junctions are also discussed, as there is an increased risk of accidents near junctions. Obstructions on the road represent a potential hazard to vehicles that veer off the road surface, and thus increase the likelihood of fatalities.

Road marking and road signage are important road infrastructure, as it greatly influences the driving experience. Obscure road markings may lead to driver error, as motorists may have an incorrect perception of the road geometry and regulations. Road surfaces can also influence fatalities of accidents, as accidents on gravel surfaces are likely to be more severe. The occurrence of road surface bleeding, which results in a smooth road surface, are also discussed. Defects in road infrastructure compromise the safety of motorists, especially at night.

The lack of illumination on the highway is also discussed, as it decreases the visibility of obstacles as well as nearby junctions. The sufficient provision of rest areas, are important in combating fatigue, as monotonous driving environments (due to non-built up areas and monotonous vegetation) exacerbate fatigue.

Civil engineering infrastructure such as guard rails and road drainage, were found to be lacking, according to the results of the investigation. The consequences of non-provision of engineering infrastructure increase the likelihood of road accidents.

### **5.2 Laingsburg Accidents for period 2000-2007**

Figure 4.24 gives a graphical representation of all the accident data for the period 2000-2007. A total of 75 fatalities occurred in the Laingsburg-Beaufort West road section, as a result of single vehicle overturning accidents. Altogether, 56 vehicles were involved in the fatal crashes. The route is predominantly a highway, with no built up land uses in adjacent areas, however, 6 pedestrian were fatally wounded in the accidents.

The research does not give an account of any animals involved in the accidents, as there were no facilities that cater for animal-drawn or pedestrian facilities. Due to the fact that only 6 pedestrians were fatally wounded in the seven year period covered, municipal engineers may see no need for pedestrian facilities, but rather mitigate any further accidents through enforcement and discouraging possibly drunk pedestrians from using the highway, especially at night when visibility is obscured.

A total of 189 people were slightly injured during this period, and the single-vehicle overturning accidents resulted in a total of 43 serious injuries. Having such a high number of fatalities and serious injuries, which may render vehicle occupants incapacitated, has severe economic consequences for the country. This is due to the fact that fatalities not only result in loss of skills and labour, but government has to compensate families of those injured on the road through the Road Accident Fund. Fatalities also serve to push families of the victims further down the poverty line, as victims were usually breadwinners, who have multiple dependents. In such cases, the government should consider paying out victims' families monthly stipends, and ensuring their children have access to education. This may prove to be controversial however, as it suggests that a price can be put on a human life.

Only 14 persons were not injured as a result of these single-vehicle overturning accidents. The objective was to eliminate or reduce the severity of these accidents. This translates to decreasing the number of fatalities, and increasing the number of persons not injured in road crashes. Although this may appear to be a difficult goal to achieve, the initial steps would be to create an environment that is suitable for motorists to perform the driving tasks.

### **5.3 Road grade**

The results from the ArcGIS show that the road grade is predominantly flat as shown in Figure 4.4. Some 32 of 55 accidents occurred on a flat road profile.

Only 1 uphill accident locations was noticed, although several unknown data points were observed.

There were no sharp curves on the route, but some slight curvature on the road was observed, which was visibly marked by warning signs at the specific locations. Schuler (1940) revealed that in cases where there are curves which are high accident risk, the curves are to be straightened out. Schuler (1940) also suggested that the super-elevation of the road should be increased in highways with high speed limit, to reduce accident rates. For the highway

investigated, the speed limit was set at 120 km/h. Road curvature was revealed to pose a problem for heavy vehicles, as it may result in rollover and side-slip accidents, especially when wind speed effects are also considered (Chen and Chen, 2010). The authors also revealed that when a truck travels on dry road surface, rollover accidents tend to occur first, especially on rural roads (highways), as this is also due to wind effects. The route investigated between Laingsburg and Beaufort West, was considered to be a rural road. The findings of the literature review and site investigation are consistent with the ArcGis analysis on roll-over accidents, as wind effects were prevalent on the N1. The risk of roll-over still exists even when the truck is not in motion. Figure 5.1 shows a warning sign for motorists to be aware of the prevailing wind effects on the highway.



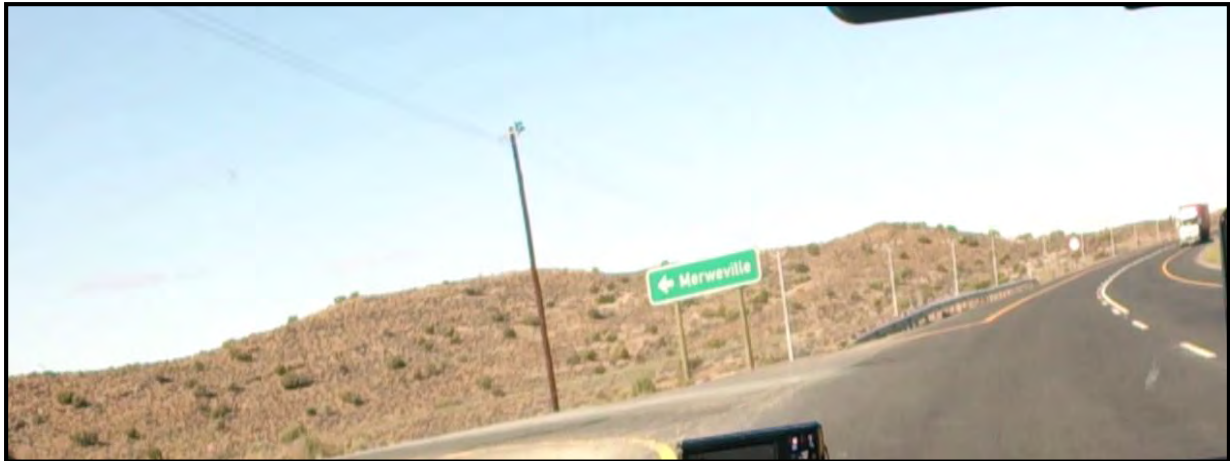
Figure 5.1: Warning sign for prevailing wind along the highway

Source: Nasiphi Dinga, 2013

## 5.4 Type of Junction

The ArcGIS analysis showed that no accidents occurred at any junctions during the period 2000-2007. According to literature, traffic calming measures are best suited for locations such as junctions, which may have high accident probability. Such measures would include rumble strips and speed humps, to warn motorists ahead of reaching the junction that a potential hazardous location is ahead. Flahaut (2004) stated that major junctions were a risk for black spots, and intersections should rather be changed to roundabouts, which would help fluidize traffic flow. The footage showed different types of junctions across the route, other than the junction previously shown by figure.

The Road Audit revealed three junctions that were perpendicular to the highway. These were located at 10-20 kilometres, 110-120 kilometres and 120-130 kilometres from the town of Laingsburg. No warning signs were observed prior to reaching the junction.



**Figure 5.2: Junction along N1 highway**

*Source: Nasiphi Dinga, 2013*

For the speed at which the vehicles travel along the national road, the junctions did not have clear warning signs which were located at safe distances from the highway. Figure 5.2 represents a dangerous access. The visibility of the junction is not ensured at night.

## **5.5 Obstructions on the road**

The ArcGis and Microsoft Excel analysis showed that there were no obstructions on the road at the time of the fatal single vehicle overturning accidents. These obstructions can be in the form of fixed objects, or human beings.

Road audit requirements stipulate that on highways with speeds greater than 100km/hour, fixed objects are to be placed at distances greater than 9 metres from the highway (Cafiso et al., 2005). Table 4.5 and Table 4.8 show that fixed objects were not placed at the stipulated distance throughout the N1 highway. These fixed objects on the side of the road present a potential hazard when vehicles veer of the road.

## **5.6 Road markings**

Figure 4.5 and Figure 4.6 show that 52 of 55 fatal single vehicle accidents occurred in areas with good road markings. However, there were several locations which had obscured road markings along the route, and this was mainly due to bleeding of the road surface. Figure 5.2 also shows that there was an obscure road marking, at 70-80 kilometres from Laingsburg.

Figure 5.3 shows part of the road markings affected by surface bleeding



Figure 5.3: Obscured road marking on N1 highway

Source: Nasiphi Dinga, 2013

Road markings form part of the transport infrastructure, which were a major component of the investigation. They served to give motorists an indication of the overtaking opportunities that were available on the stretch of road being investigated, hence them being compromised by surface bleeding poses a major threat to motorists. This is further exacerbated at night-time when visibility is also minimal. Due to the nature of the single-carriageway, the most important feature investigated in terms of road markings was thus the presence of a barrier line. According to Vanderschuren and Jobanputra (2011), 40% of accident locations had a missing barrier line. With respect to the route under investigation, a missing barrier line occurred in only 20% of the fatal accident cases. This was shown in the excel analysis in figure 4.15.

## 5.7 Road surface

At the time of accident occurrence during the period 2000-2007, the road surface was revealed to be dry. This could be due to the prevailing weather conditions on that particular day. The site audit was conducted under sunny weather conditions, which also affected the credibility of the results. In case of inclement weather conditions, road drainage facilities would have been important to remove any water on the road surface which might compromise the safety of vehicles. The ArcGIS analysis also revealed that the accidents took place on tarmac material, which was the material that the road surface is made of. The ArcGIS analysis also revealed the road surface at time of accident occurrence, with no visible potholes and bumpy road surface. There were several road sections which suffered from road surface bleeding, as shown in the figure 5.4. According to Noland (2003), provision of more paved road per capita lessens fatalities, but the provision of more road space for vehicles is

shown to increase fatalities. This is due to higher travel speeds that may be achieved on rural roads with more road space, which in turn lead to more accidents.

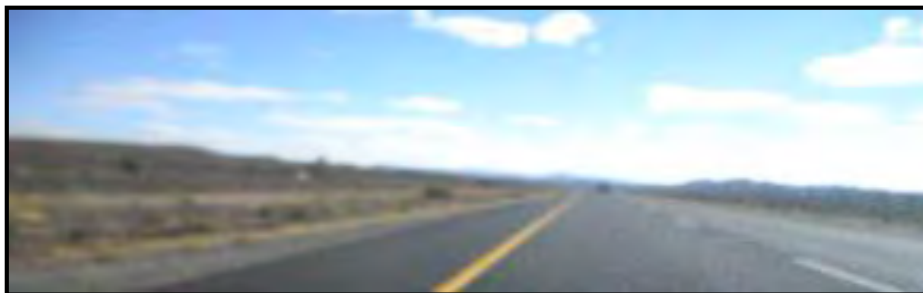
Road surface bleeding also affects the driving experience as there is less friction between the vehicle and road surface. Observations of surface bleeding were made at 10-20 kilometres and 110-120 kilometres as shown in Table 4.5 and Table 4.8.



**Figure 5.4: Road section affected by road surface bleeding**

*Source: Nasiphi Dinga, 2013*

Figure 4.16 of the road audit shows that four observations were made indicating a presence of a gravel shoulders. These were at 10-20 kilometres, 50-60 kilometres, 80-90 kilometres and 110-120 kilometres. The average width of road shoulders was also greater than 0.5 metres, as observed in the audit. The edges of road shoulders were observed to be made of gravel material (stones), and not hard shoulders. The figure 5.5 shows the material used in constructing the road shoulders.



**Figure 5.5: Gravel material on edge of road shoulders**

*Source: Nasiphi Dinga, 2013*

This could prove to be a problem to vehicles that veer of the road, as vehicles tyres might not provide sufficient grip on the road surface. This in turn can lead to single-vehicle overturning accidents during inclement weather conditions such as excessive wind or icy roads.

## **5.8 Built-up area**

The road environment greatly affects the driving experience. The ArcGIS analysis showed that 36 out of 55 accidents occurred in built up areas, and that 19 of the 55 did not occur in built up areas. This was actually a surprising result because the location was in a desert environment, with a small number of built up land uses visible.

Results of the road safety audit showed that built up areas were located at 20 – 30 kilometres, 100 – 110 kilometres and 110 – 120 kilometres as shown by Table 4.5 and Table 4.8. These built up areas were in the form of informal housing in the desert terrain and did not provide a variable road environment.

## **5.9 Road signs**

The road signage, which included warning and information signs, was revealed to be in good condition according to the ArcGIS analysis. This was further shown to be the case when the Road safety audit was conducted, with road signs located at required heights to ensure visibility to motorists. They were however located too close to the carriageway, which posed as a potential obstacle should a vehicle veer off the road, hence worsening the severity of possible accidents. Road signs should be located about 9 metres from the carriageway instead of 3 metres from the carriageway.

Moreover, it should be noted that road signs form part of the road infrastructure, which contribute towards to making a safer road environment. Geometric design standards dictate that road signs are to be placed at locations where the road geometry is not sufficient to achieve safe standards; hence motorists are warned beforehand of any driving manoeuvres that have to be adjusted.

Figure 5.6 shows the location of road signs relative to the single-carriageway highway. This image clearly shows that the road signs are located too close to the carriageway. This renders them a high risk problem as road signs have the potential of being an obstacle that worsens the severity of a collision, should a vehicle veer of the road. They also have the potential of obstructing the motorists' line of sight.



**Figure 5.6: Road sign location relative to the highway**

*Source: Nasiphi Dinga, 2013*

Table 4.6 and Table 4.9 reveal that road signs were located where necessary, and did not obstruct visibility of motorists. However, there was a lack of warning and information signs near junctions, which were observed in the road audit.

## **5.10 Streetlamps**

Table 4.6 and Table 4.9 of the road audit reveal that street lighting is only located in the 0-10 kilometre section of the highway. The lack of street lighting is shown in figure 5.7. Insufficient lighting is a problem for motorists who use the highway, especially at night. Not only will motorists not be able to see pedestrians travelling on the highway at night, but other hazardous objects and important information signs may be missed. Currently, the reflectors on the road surface can be observed, but these are not sufficient to provide proper illumination. The presence of streetlighting may serve to both reduce accidents and accident severity, especially at night.



**Figure 5.7: Absence of streetlighting on the N1 highway**

*Source: Nasiphi Dinga, 2013*

Due to the length of the road section (> 200km), illumination would require copious amounts of energy. The looming energy crisis in South Africa renders it uneconomical to provide energy along the entire route. However, alternative methods to mitigate accident severity (solar powered lighting) can be utilised.

## 5.11 Rest areas

Rest areas are located every 10 kilometres on the highway, for use by fatigued motorists as shown in Table 4.6 and Table 4.9. These tables also revealed that there were sufficient parking bays at the rest areas. However, the route is also frequented by heavy vehicles such as trucks, carrying freight between Johannesburg and Cape Town. These heavy vehicles also make use of the rest areas. Figure 5.8 shows a truck that is parked in one of the rest areas.

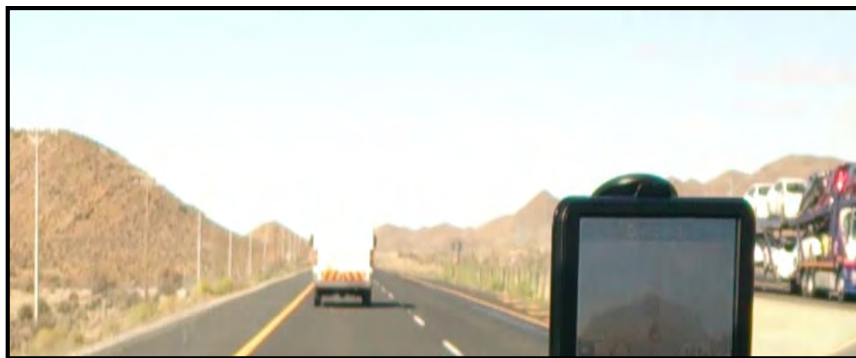


Figure 5.8: Truck occupying entire rest area along the N1 highway

Source: Nasiphi Dinga, 2013

It can be deduced that these rest areas do not provide sufficient parking for passenger vehicles and trucks alike. However, due to the fact that the rest areas are located every 10 km, motorists can make use of other unoccupied stalls. These areas are also to be monitored frequently as truck drivers can take advantage of the rest stops and park their vehicles for extended periods of time, thereby leaving motorists with no places for taking recesses.

## 5.12 Drainage facilities

Table 4.7 and Table 4.10 reveal that drainage infrastructure was located at 0-10 kilometres, 110-120 kilometres and 190-200 kilometres. Other locations in the highway did not have drainage facilities.

Drainage facilities are important in the efficient removal of water from the road surface. The removal of water prevents skidding and hydro-planing of vehicles.

Cambering of the road surface was also observed, as shown in Table 4.5 and Table 4.8. This allows for drainage of water on both sides of the road.

It would not be cost-effective to provide drainage facilities for 200 kilometres of highway, although alternatives should be considered. This is mainly due to flooding incidents in Laingsburg in January 1981 and more recently, January 2014. These flooding incidents led to road closures of the highway, which limited access to surrounding areas in Laingsburg.

Natural drainage facilities such as water channels, as well as vegetation which provides flood protection, should be considered on the highway.

### **5.13 Guardrails**

Guardrails were observed at four locations on the highway, mainly at 100-110 km, 120-130 km, 160-180km and 190-200 km. Guardrails protect vehicles for straying off the road space. It was therefore expected that the highway would have guardrails located at regular intervals on the highways. This infrastructure would lower single vehicle overturning accidents on the N1 between Laingsburg and Beaufort West, by providing a protective barrier.

### **5.14 Vegetation**

Figure 4.19 reveals that vegetation found on the highway was monotonous. Variable vegetation, in the form of trees, was only found at locations 0-10km, 20-30 km, 110-120 km, and 190-200 km. These locations were mostly near rest stops. A monotonous driving environment may exacerbate fatigue, resulting in an accident.

The observations of the road showed that the vegetation was consistent with that found in a desert area. In case of a natural disaster, this vegetation would not offer flood protection by absorbing the flood water.

## **5.15 City of Cape Town fatalities**

The City of Cape Town fatalities showed an increase in number for the subsequent years, 2010 (14 estimated fatalities) to 2013 (31 estimated fatalities). Therefore, the accident reduction goals of the Western Cape provincial government were not realised as yet in the City of Cape Town. However, these results are for one Municipality and do not reflect the overall results of the Provincial Government of the Western Cape fatal accidents, during the 2009 to 2014 period.

Pedestrian fatalities were observed mainly in the Khayelitsha area, and these may warrant a pedestrian bridge and sidewalks.

## **5.16 Chapter Summary**

This chapter discusses the findings of the geographical analysis, road safety audit, as well as City of Cape Town data analysis.

The road gradient was predominantly flat, with no sharp curves observed during the road audit. There were no accidents that were recorded at the junctions, although dangerous at grade intersections were observed during the road safety audit.

Fixed objects were located at distances less than 9 metres from the highway, although the geographical analysis revealed that there were no obstructions on the road at the time of fatal accident occurrence.

The road markings were in good condition, as well as the road surface, although road surface bleeding was observed during the audit. Gravel shoulders were also observed, which are undesirable for errant vehicles, as they have less road recovery space.

Accidents occurred on built up adjacent land uses, although the road safety audit revealed few built up adjacent land uses on the highway.

There was also no highway illumination, which may be problematic at night. Guardrails are located at few locations, which is not ideal for the road section which is classified as a hazardous location.

The vegetation observed during the road audit is monotonous, and it may affect the driving experience. Soft engineering measures like the planting of variable vegetation, would improve the driving experience, as well as provide a barrier for errant vehicles.

The analysis of the 2010-2013 SANRAL data revealed that the City of Cape Town had an increase in road accidents, and that there were significant pedestrian fatalities on the N2 near Khayelitsha.

## **6. Conclusions**

### **6.1 Introduction**

This chapter aims to conclude on the findings of the research. Conclusions will be based on the findings of the geographical analysis, as well as the road audit, as well as the SANRAL City of Cape Town data. Infrastructure and geometrical factors, which affect the prevalence of single vehicle accidents, are also discussed.

### **6.2 Infrastructure provision influences road safety**

Infrastructure is an important component of road safety for both motorized and non-motorized traffic. The literature review revealed that pedestrian accidents can be decreased through the provision of marked pedestrian crosswalks, as well as signalized crosswalks. For vehicular accidents, the literature review revealed that improving infrastructure through the increasing of lane widths does not provide any road safety benefits. Data from the iPas system, provided by the PGWC, revealed that there were no visible infrastructure problems, when analysed through ArcGis. Road signs and road markings were in place, and in good condition, at the fatal accident locations. Therefore, the relationship between infrastructure and single vehicles overturning could not be determined. The road safety audit, however, revealed a lack of guardrails in the road section between Laingsburg and Beaufort West. The purpose of guardrails is to provide a barrier for errant vehicles. The close proximity of utility poles and road signs was also observed during the audit, as these may exacerbate the severity of accidents.

The lack of pedestrian infrastructure in the City of Cape Town is a contributor to the frequency of pedestrian fatalities. The ArcGis analysis revealed the locations where there was a high incidence of pedestrian accidents in Appendix Q. There is no pedestrian infrastructure in the Laingsburg N1 as well as within the hotspots identified within the City of Cape Town municipality.

There were a small number of trees and vegetation observed during the road audit. Trees and vegetation are road infrastructure which help in providing a variable and stimulating driving environment, and decreasing monotony in the driving experience. It can thus be said that infrastructure is a major contributor in road accidents.

### **6.3 Road geometry important for reducing road accidents**

The literature review revealed that for routes having rural two-lane roads, the lane width is an important factor for increasing the safety (Karlaftis et al, 2002). Narrow lanes result in the decrease of vehicle operating speed, and this result can be transferred to the Laingsburg-Beaufort West case, which is a rural two lane highway. The existence of side accesses also provides significant safety benefits, as motorists tend to lower their speeds when approaching junctions. The geographical analysis revealed that the majority of fatal accidents did not occur at junctions. The road audit, however, did reveal a number of dangerous accesses adjacent to the highway.

Ogden (1997) also revealed that paved shoulders provide recovery space for errant vehicles, thus decreasing single vehicle overturning accidents. The road surface was in good condition, as revealed by the geographical analysis, as well as road safety audit. However, gravel shoulders having average width of 0.5 metres, may be detrimental for road users, as there is insufficient recovery space for vehicles. The road was predominantly flat, as shown in the research findings, as well as road safety audit. However, Bhatti et al., (2010) did illustrate the rural accidents had a high frequency on flat road surface. A flat road surface, combined with wind effects (Chen and Chen, 2010) may result in single vehicle overturning accidents.

These findings are relevant towards the prevention of single vehicle overturning accidents, as improving on these features would reduce fatal accident occurrence.

### **6.4 Single vehicle overturning accidents have a higher incident rate**

The primary purpose of the research was the analysis of single vehicle overturning accidents on the N1 between Laingsburg and Beaufort West. Data for the year 2000 to 2007 retrieved from the iPas system, was analysed using ArcGIs, with a subsequent road safety audit. Figure 4.1 showed that there were 55 **fatal** single vehicle overturning accidents, over a total of 130 accidents along the road section. This accident type had a higher occurrence than all other accident types that were in the iPas system. This further supports the research objective, which was to determine whether there was more single vehicle overturning accidents in the Laingsburg Beaufort West study area, than all other accident types. The high frequency may be due to the road geometry (narrow road shoulder width) as well as road infrastructure (lack

of guardrails), which exacerbate these accidents and result in more fatalities. Out of the 55 single vehicle overturning accidents, 75 fatalities were recorded.

## **6.5 Geographical data insufficient to analyse accident contributory variables**

There were several missing data points in the iPas system data. As a result, a geographical analysis of the data could not determine the distinct variables that contribute towards single vehicle overturning accidents. The geographical data also did not include the road shoulder width, road shoulder paving, distance of utility poles from highway and presence of guardrails at the accident locations.

Problems regarding traffic data collection are discussed in depth by Thwala (2012), who describes road accident data in South Africa as being ‘randomly missing, uninformative, partially informative or even misleading’. Salifu et al., (2011) also revealed that for less severe accidents, the likelihood of non-reporting increases. However, fatal accidents are always reported to the police.

The PGWC data may thus be affected by administrative errors or non-reporting. This results in a skewed representation of the factors that lead to accidents, as the geographical analysis could not determine the factors which result in single vehicle overturning accidents, hence a road audit was necessary.

## **6.6 PGWC accident reduction goals not achieved in CoCT**

The Safely Home project, implemented by the PGWC in 2009 aimed to reduce road accident by 50% by 2014. The City of Cape Town accident data, therefore provided a representative sample for the analysis of the objectives of the project. For the period 2010, there were 14 fatalities, 2011-44 fatalities, 2012 – 80 fatalities, and 2013 had more than 13 fatalities. This represents an upward trend in fatal accidents in the municipality. However, the sample is too small to draw inferences on the success of Safely Home Campaign. There is also a high incidence of pedestrian accidents along the N2 near Khayelitsha, owing to a lack of pedestrian infrastructure such as pedestrian bridges, as well as grade separated walkways.

## **6.7 Chapter Summary**

This chapter concluded on the research questions posed in Chapter 1. It reiterates that road infrastructure does in fact influence road safety. In Laingsburg, the road infrastructure to be improved includes guardrails, as well as the relocation of road signs from the single carriageway.

The road geometry in terms of shoulder width and paving were found to be insufficient to provide any safety benefits. However, the presence of side accesses was observed, and these result in a speed reduction of approaching vehicles on highways.

The research revealed that single vehicle overturning accidents have a high incidence rate on this N1 road section. The geographical data does not provide adequate information on the infrastructure and geometrical features necessary for further analysis.

The reduction of fatal accidents by 50% within the City of Cape Town has not yet been achieved, as an upward trend in fatalities was observed in some years.

The research also revealed a high incidence of pedestrian accidents in the City of Cape Town.

## **7. Recommendations**

Based on the conclusions in chapter 6, the following recommendations are suggested.

### **7.1 Improved infrastructure planning**

The main infrastructural problems identified in the research include insufficient guardrails along the route, as well as the close proximity of road signs and utility poles. The installation of guardrails along the route may not be cost effective, but may provide significant safety benefits. The relocation of signs and utility poles should also be considered, to lessen the severity of potential accidents.

Soft engineering infrastructure must also be implemented, to provide a variable driving environment, and decrease monotony on the highway. The planting of trees and vegetation to create a variable driving environment, may also act as a barrier for errant vehicles. To increase the safety of pedestrians, pedestrian bridges, as well as pedestrian walkways, are necessary within the City of Cape Town, especially near Khayelitsha.

### **7.2 Improved consistency of geometric design to reduce highway accidents**

The research has shown that geometric conditions are an important component of road safety. To decrease the frequency of single vehicle overturning accidents, the road shoulder pavement is to be increased from the current average width of 0.5 metres, to provide recovery space for errant vehicles. The existence of side accesses is also an important aspect of road safety, as vehicles tend to decrease their speed when approaching intersections. The intersections observed during the road safety audit were considered to be dangerous, as there was no advanced warning to motorists. Providing illumination at these locations, as well as warning signs (reflective signs), is recommended.

Owing to the fact that wind may contribute to overturning accidents (Chen and Chen, 2010), planting of trees is further shown to be important as a decrease in wind effect may be experienced by motorists as excessive wind warning signs were observed during the road safety audit. Trees and vegetation, therefore, are necessary for providing a variable road environment, as well as decreasing the effect of wind on vehicles.

### **7.3 Implementation of better data collection measures**

An improvement of road accident data collection is necessary. The frequency of missing and unknown data points can be decreased through the training of traffic officials, and medical personnel, who are usually first on the scene at accident locations. A centralized system, which allows for easy data capturing and access to accident records can greatly improve road accident data collection.

To decrease the instances of non-reporting, a combination of education and enforcement may be beneficial. The public, and officials, must be educated on the importance of reporting accidents, even non-fatal accidents. This will greatly improve the quality of the data. Providing penalties for non-reporting through hefty fines, may also encourage the reporting of accidents.

### **7.4 Further research on highway accidents in the Western Cape**

Further research should be considered, especially within the City of Cape Town.. Further research is necessary to observe existing gaps in the research, as well as to hold Transport Bodies such as PGWC and SANRAL accountable for their goals. Research in this field may also help to identify road accident mitigation measures which are successful, as well as identify areas which need improvement.

Updated data, which includes all Western Cape municipalities, should be obtained and analysed, in order to achieve a level of confidence in the data upon analysis. Obtaining updated data, as well as training traffic officials to capture the data, will help decrease the gaps ('unknown data points) that were found in the geographical analysis.

### **7.5 Chapter Summary**

This chapter gives recommendations based on the research findings. These are in the form of relocation of poles, installation of guardrails, planting of vegetation across the N1 highway.

The collection of road accident data should be improved through the training of traffic officials who are first on an accident scene. Penalties for non-reporting of accidents, should also be considered. Fatal and non-fatal accidents should be available for analysis by researchers.

Increasing pavement width is also recommended, to increase the recovery space of errant vehicles. The provision of illumination at the existing side accesses is strongly recommended, to improve their visibility. The planting of vegetation to provide a stimulating road environment is also recommended.

Further research is suggested within the City of Cape Town municipality, as well as any sections that have high accident rates.

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# Appendix A

Inspection Checklist				
Highway Number <u>N4</u> from km <u>000</u> to km <u>000</u> Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
1. Function, operating elements and surrounding	1	Are there any information about previous RSE?	X	
	2	Are there any issues from accident data if available?	✓	no accident in this section
	3	Are there specific traffic composition characteristics to be taken into consideration (e.g. pedestrians in through road sections)?	X	As pedestrians observed
	4	Are special measures required for particular groups e.g. for young people, older people, sick people, physically handicapped, hearing-impaired or blind people (through road section)?	✓	
	5	Is the design of the road according to its function and hierarchy in the network?	✓	Interurban Highway
	6	Are there build up areas with mixed traffic?	✓	
	7	Is access to abutting properties and agriculture appropriate for road safety along the interurban section, are these safe?	X	
	8	Are there any parallel ways to be used by carts and farm equipment?	X	
	9	Do we realize the change of functions and characteristics early enough (orientation sight)? 100 km/h ► 300 m ahead 80 km/h ► 200 m ahead 60 km/h ► 120 m ahead	✓	No problem with transition
	10	Are there anywhere accumulations of events such as curves + humps + intersections etc?	✓	Not found
	11	Are transitions installed between different functions and road characteristics?	X	
	12	Are there traffic islands and lane shifts at the entrance of villages and towns?	X	
	13	Are speed limits required and applied in the best way?	✓	100 km/h
	14	Is stopping sight distance guaranteed along the entire section? (for 100km/h= 170 m, 80 km/h =110 m, 60 km/h=65 m, long fall = 0%)	✓	
	15	Is overtaking sight distance in an acceptable percentage (about at least 20%) of the road section ensured? (for 100 km/h ► 300 m ahead, for 80 km/h ► 200 m ahead, for 60 km/h ► 120 m ahead)	✓	
	16	Are all fixed or planted obstacles that can be dangerous placed outside the safety zone? 100 km/h ► 5m 80 km/h ► 6m 60 km/h ► 3m (away from skidding cars?)	✓	Roadside 2.3m from highway
	17	Is the transition from a built-up to a rural road or from an illuminated to a not illuminated road appropriately designed (village/town outskirts)?	X	
2. Cross section	1	Is the cross section appropriate to the function?		
	2	Does the road surface provide the required grip over the long term where small ruts occur?	✓	No small ruts or sharp changes observed
	3	Are there any doubts regarding the surface grip because of excess bleeding or polished components?	✓	10-20km @ 110-120km small ruts observed

Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	4	Is the surface even and free from grooves, ruttings, potholes?	✓	Surface good until 10.2 km 10-11.0 km (surface bleeding)
	5	Is the surface free from short or long waves?	✓	
	6	Is there sufficient drainage for the road and its surrounding?	X	Drainage at 8-12 km and 10-12 km, 190-200 km
	7	Is there sufficient superelevation in curves, long fall and diagonal fall in the case of the change of the direction of the cross fall?	✓	Proportionally flat that
	8	Is the cross fall in straight sections constant?	X	And uneven, consider height
	9	What is the medium width of the road shoulders?	OK	Some section 7.00-8.00 m 1.00-2.00 m at 100-120
	10	Are there stable shoulders (like hard shoulders or gravel shoulders)?	Mid	Just at 10-12, 50-100 110-120 km
	11	Are the shoulders and the carriageway at the same level?	✓	
	12	Have sufficient measures been taken on cutting slopes to prevent falling material (e.g. falling rocks)?	N/A	
	13	Is stopping sight obstructed, for example by narrow crest curves?	X	
	14	Is narrowing of the carriageway required and, if so, designed in such a way to ensure traffic safety?	X	Irregularly for 100-120
	15	Have suitable measures been taken to ensure that speed limits are obeyed?	X	by 100 km/h
	16	Have the needs of public transport and its users been taken into consideration?	X	No P.T.
	17	Is slow and non motorized traffic separated from fast and heavy traffic (e.g. separate facilities)?	X	
	18	Is there a median? Does it have a safe design, e.g. safety barrier or sufficient width to prevent head on collisions?	X	No median convenient
	19	Are there any bottlenecks? If so, are they properly signed?	X	
	20	Do curves with small radii have an enlarged width of the pavement?	X	Curves with small radius
	21	Does the embankment or obstacles beside the road require passive safety installations?		
3. Alignment	1	Is the existing speed limit adequate for the horizontal and vertical elements of the alignment?	✓	
	2	Is sight obstructed, for example by safety barriers, fences, road equipment, parking areas, traffic signs, landscaping/greenery, bridge abutments, buildings?		20m sight distance but obstacles too close
	3	Is visibility in curves ensured?	✓	
	4	Are there sufficient overtaking possibilities?	X	Overtaking only in curves
	5	Has the uphill sector a passing lane for overtaking down traffic?	N/A	

Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	6	Has the passing lane a sufficient length in order to insure that the vehicles can overtake and return safely?	X	230 passing not considered
	7	Are arrester beds necessary in downhill sections (depend on the percentage of heavy trucks and the gradient)?	X	Not considered
	8	Are there hidden dips in the vertical alignment?	X	N/A
	9	Is the alignment consistent and easily recognized by the road users? Or full of „surprises“ for the drivers?	✓	Alignment consistent
	10	Are changes (surprises) indicated by transitions like signing, points of fixation?	✓	Signatures along for surprises (wind)
	11	Are the outside of the curves framed parallel and consistent?		
	12	Are the insides of curves free from side obstructions (lateral clearance)?		
	13	Are there optical illusions?	✓	Rd-shoulder markings not clear?
4. Intersections	1	Are the intersections perpendicular?	✓	0-100m, 80-120m 110-120m, 120-130m
	2	Is the main direction clearly recognizable? And if so, is the right of way clearly recognizable?	X	
	3	Are the movements guided clearly and easily to understand? Are traffic flows guided by markings?	X	N/A - 100m, 120m, 130m
	4	Are the auxiliary lanes or tapers for left, right and U-turning movements large enough?		N/A
	5	Is the intersection fully visible and recognizable in time from all approaches for different driver eye heights of: Cars, trucks, motorcycles, bicycles, etc. and are the required sight triangles clear?	X	
	6	Does the ambient lighting present any special requirements (e.g. imitation for traffic signals)?	X	No lighting
	7	Is sight obstructed at intersections, for example by safety barriers, fences, road equipment, parking areas, traffic signs, landscaping/greenery, bridge abutments, buildings?	N/A	
	8	Are type and design of the intersections suitable for the function and traffic volume of the intersecting roads? (Separate answers for each intersection!)	X	unsuitable intersections
	9	Is pedestrian/cyclist routing at intersections adapted to the actual conditions and clearly marked and signposted?	X	N/A
	10	Are all approaches equipped with pedestrian and bicycle crossings?	X	
	11	Is the transition safely designed if footpaths and cycle paths end on a intersection or road or are directed across the road?	X	Dangerous intersections

<b>Inspection Checklist</b>				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
Intersections continued	12	Have suitable measures been taken to ensure that speed limits are obeyed?	X	only road
	13	Is a reduction in speed required in the direction of the intersection? And are there transitions for speed reductions on the minor road?	X	side road
	14	Does the obligation to yield right of way need to be reinforced (e.g. using repetition)?	✓	
	15	Are pedestrian crossings clearly marked? Is each section equipped with signals (including railway structures)?	X	NONE observed
	16	Are the crossings for pedestrians and bicyclists provided with low kerbs?	✓	At 0-10 km
	17	Are the type and spacing of different crossing installations coordinated (e.g. railway crossings, traffic signals, zebra crossings)?	X	N/A
	18	Are refuges long and wide enough for crossing pedestrians and bicyclists to stand and wait?	✓	@ 0-10 km
	19	Are the islands above the level of the carriageway (curbed islands)? or only made by markings?	no-isle	
	20	Is there a danger of underestimating speed and overestimating distance of crossing vehicles?	✓	through out all approach road - low limit
	Roundabouts	21	Are the islands clearly visible and of a suitable design?	
22		Are all approaches to roundabouts radial to the centre? Is the design suitable to ensure a low speed level and support the right of way?		
23		Is there a sufficient deflection to ensure an appropriate speed when passing the roundabout?		
24		Is the central island of the round about shaped as a hill?		
25		Is the through-visibility effectively stopped by the round about and the hill?		
26		Is the central island of the roundabout free of fixed obstacles which could be reached by vehicles?		
27		In the case of a high number of powered two wheelers: ensure the road surface an sufficient grip?		
28		Is a low speed level supported by constructional measures and by way of marking?		
5. Traffic signals	1	Is the stopping line correlated with the traffic signal so that the signal can be seen?		
	2	Have any turning movements been excluded from signal control? If so, is traffic management safe?		
	3	Are traffic signals easily recognizable, are there repeating/doubled signals?		
	4	In areas with bicyclists: Have bicyclists' requirements been considered (e.g. route through the intersection)?		
	5	In areas with bicyclists: Are stop lines for motorists set back for the benefit of bicyclists?		

<b>Inspection Checklist</b>				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	6	In areas with pedestrian traffic: Are all approaches equipped with pedestrian and cycle crossings?		
	7	In areas with pedestrian traffic: Are pedestrian crossings clearly constructed? Is each section equipped with signals?		
	8	Are exclusive green phases provided for pedestrians and bicyclists where necessary?		
	9	In areas with pedestrian traffic: Can pedestrians cross the road in one go? Is the green time sufficient?		
	10	In areas with pedestrian traffic: If there is no exclusive pedestrian phase, is a leading pedestrian interval provided?		
	11	In areas with pedestrian traffic: Are phase offsets required for pedestrians and bicyclists within the running cycle?		
	12	Are the type and spacing of different crossing installations coordinated (e.g. railway crossings, traffic signals, zebra crossings)?		
	13	Are the signals affected at dawn/dusk by direct sunlight?		
	14	Are advanced warnings provided for traffic signals that cannot be seen in time?		
	15	Have the locations for the signals been selected correctly (additional signals, overhead signals, etc.)?		
	16	Does the existing road lighting lead to conflicts in recognizing the yellow indication (sodium discharge lamps)?		
	17	Is access from abutting properties affected and, if necessary, included in signal control?		
	18	Are risks avoided for a "see through effect" by highlighting the nearest signals?		
	19	Are the traffic signals properly situated so that they can be distinguished by each particular traffic flow?		
	20	Are there any additional signs correlated with the traffic signals to show the direction to which that traffic signal is referring to?		
	21	Is the visibility of the traffic signal ensured on a sunny day?		
	22	Is the stopping line correlated with the traffic signal so that the signal can be seen?		
	23	Are signals covered/ obstructed (e.g. by traffic signs, lighting masts, plants, traffic jams)?		
<b>6. Railway crossings</b>	1	Is the type of the railway crossing according with the traffic volume?		
	2	Are passive safety devices at the required locations?		
	3	Are the traffic signs correlated with the type of railway crossing?		
	4	If the railway crossing is situated in a curve are the traffic signs doubled on the other side of the road?		

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July 2009

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Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	5	Are traffic control devices required and optimally set up with regard to future traffic developments?		
	6	Is the perception from a sufficient distance guaranteed?		N/A
	7	Is good visibility guaranteed?		
	8	Is lighting required and appropriately installed?		
	9	Does the ambient lighting present any special requirements?		
	10	Are prohibition of overtaking and speed limits in place as necessary?		
<b>7. Services and rest areas</b>	1	Are service and rest areas and parking facilities on both sides of the road? In case not, are there left turn lanes?	✓	
	2	Are there deceleration and acceleration lanes or tapers at the entrance and exit?	✓	2 km, 100 m
	3	Is the number of the parking areas for parking for passenger vehicles, trucks and buses sufficient?	X	to fully busy
	4	Are the dimensions of the parking areas sufficient for parking for passenger vehicles, trucks and buses?		
	5	Are areas for buses and passenger cars separated from the truck traffic (in the case of large rest areas)?	X	
	6	Are the layout and cross section of the service or rest area appropriate for the different traffic movements? And if so, is layout suitable in access areas to and from?		
	7	Is the layout in such a way, that vehicles are running at the appropriate speed?		
	8	Are the parking areas physically separated from the carriageway (guardrail, kerb, green area etc.)?	X	
	9	Are there safe footpath connection to restaurants, rest rooms etc.(including safe crossings of) ?	X	
	10	Have measures been taken to ensure safe access for rescue vehicles/maintenance vehicles/fire service?	✓	Police?
	11	Are sufficient parking areas provided to minimize illegal parking on footpaths and on the carriageway with the corresponding hazards or have corresponding preventative	X	Police, road
	12	Is sight obstructed by parking areas or by illegally parked vehicles?	X	
<b>8. Needs of vulnerable Road</b>	1	Are stops easily and safe accessible to pedestrians (combination with pedestrian crossings; crossing help,		

<b>Inspection Checklist</b>				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
<b>users</b> <b>8.1 At Public transport stops</b>		footpaths connection etc.)?		
	2	Are the bus stops signposted and detectable by the drivers? Is recognisability from a longer distance guaranteed?		
	3	Are the bus stops situated outside of the carriageway where appropriate?		
	4	Are the queuing areas for waiting passengers sufficient?		
	5	Is sight obstructed, for example by safety barriers, fences, road equipment, parking areas, traffic signs, landscaping/greenery, bridge abutments, buildings?		
	6	In the case of bicycle paths: Is cyclist routing safely designed in the area near public transport stops?		
<b>8.2 Other needs of Pedestrian</b>	7	Is lighting required? And if so, is it appropriately designed?		
	1	Are the pedestrian crossings located where most required by pedestrian traffic?		
	2	Have pedestrian crossings been appointed in such a way that collective use is guaranteed and the road will not be crossed at other points?		
	3	Is there a risk of pedestrian underpasses and bridges being bypassed? Are suitable measures in place?		
	4	Are further crossing aids required?		
	5	Are areas for waiting pedestrians and cyclists sufficient?		
	6	Are refuges large and wide enough for crossing pedestrians and bicyclists to stand and wait?		
	7	Are crossings over special railway structures of a safe design?		
	8	Is two-way visual contact ensured between pedestrians and motorists?		
	9	Are the pedestrian ways physically separated by kerb stones, barriers or greenery?		
	10	Are the pedestrian crossings signposted and detectable by the drivers?		
	11	Are the islands clearly visible and properly placed?		
12	Is lighting provided where necessary?			
<b>8.3 Bicyclists</b>	13	Are there separate bicycle facilities?		
(only in the case of existing facilities)	14	Are dimensions and pavement suitable?		
	15	Have cyclists' requirements been considered (e.g. route across central refuges, bottlenecks)?		
	16	Is the visibility for motorised traffic adequate to see cyclists along the road?		

Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	17	Are parked vehicles obstructing the visibility of the road users regarding cyclists?		
	18	Are points where cyclists cross intersecting roads provided with low curbstones?		
	19	Is right of way clearly defined at points where cyclists come into contact with each other or with motorized traffic?		
	20	Is it clear to the motorist whether he is crossing a one-way or two-way cycle path?		
	21	Are advanced warnings in place for features that cannot be seen in time?		
	E.4 Needs of motorcyclists	1	Are motorbikes a remarkable percentage of the traffic?	
2		Have devices or objects that might destabilise a motorcycle been avoided on the road surface?		
3		Is the road side clear of obstructions where motorcyclists may lean into curves?		
4		Will warning or delineation be adequate for motorbikes?		
5		Have barrier kerbs been avoided in high speed areas?		
6		In areas more likely to have motorcyclists run off the road is the roadside forgiving or safety shielded?		
9. Traffic Signing, Marking, Lighting 9.1 Signing	1	Have appropriate speed limits been signed appropriately (start, end, height, location)?	✓	
	2	Are there speed limitations ahead of intersections and build up areas and in through road sections?	X	Highway intersection
	3	Is the visibility of the road course assisted by edge delineation?	✓	yellow kerb
	4	Is sight obstructed by the traffic or by the signs?	X	signs too close to carriageway
	5	Is prohibition of overtaking for trucks, buses, etc. appropriately designed and located? Are there warning signs ahead of the intersection prohibiting overtaking?	X	
	6	Can the signs be clearly recognized and read (size of sign)? And do the signs conform to the conventions of Vienna and Geneva?	✓	
	7	Are there more than 2 different traffic signs at one place?	X	
	8	Is a reduction in speed when approaching the intersection assigned to the correct place and properly designed?	N/A	
	9	Is signing logical and consistent? Does it show the right of way clearly?	X	
	10	Is signing for service and rest areas clear?	✓	Signs avoided before approaching rest area

Inspection Checklist			
Highway Number ..... from km ..... to km ..... Date:			
Characteristic	No.	Question	Yes (✓) No (X) Comments
Traffic signing continued	11	Could greenery lead to safety problems if the vegetation grows (e.g. as a result of covered road signs)?	X No greenery present with clear signs
	12	Are signs located in such a way as to avoid restricting visibility from approaches or intersecting roads?	✓ Signs too close to oncoming!!
	13	Is the roundabout fully visible and recognizable from all approaches and are the markings and signs clear and unambiguous?	N/A
	14	Are signs retro reflecting or are they illuminated at night? In daylight and darkness, are signs satisfactory regarding visibility?	✓
	15	Are the additional information panels uniform?	N/A
	16	Are there misunderstanding or misleading traffic signs or additional information panels?	X
	17	Is readability ensured at the required distance? Are there background problems?	✓
	18	Where needed have signs been located above the carriageway?	✓ Warning sign @ (40-50km), Start spot sign @ (0-10km)
	19	Do the signs have a dimension according to the type of road?	?
	20	Are the signs provided with protective edges?	X
	21	Are the signs at a uniform position, compared to the pavement?	✓ Uniform for 100 km
	22	Are the sign inlets and foundations sufficiently protected against collisions?	X
	23	Do the traffic signs including their supports have a sufficient passive safety by: low mass or/and? Break away structure or/and? Are they beyond the safety zone? Passive safety installations?	N/A
24	Do delineators have a break away structure?		
9.2 Markings	1	Do all signs and markings correspond without any contradictions?	✓
	2	Are the road markings clear and recognizable?	✓ Clear @ 40-50km
	3	Have old markings/signs been completely removed (phantom markings)?	✓
	4	Are the markings in a parallel line to the edge of the road surface?	✓
Marking continued	5	Are the markings appropriate for the function and category of the road?	✓ Rev overlooking opportunities

Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	6	Are the markings likely to be effective under all expected conditions (day, night, wet, dry, fog, rising and setting sun)?	✓	
	7	Is the obligation to yield right of way enforced by markings according to the one enforced by signing?	X	Not necessary
9.3 Lighting	1	Is the road sufficiently illuminated? Is there a need to have illumination?	X	only lighting only 10-20km, 190-200km
	2	Is the stationary lighting appropriate?	N/A	
	3	Is the lighting of special situations (transition zones, changes in cross section) suitably designed?	N/A	
	4	Does the existing road lighting lead to conflicts in recognizing the yellow indication (sodium discharge lamps)?	N/A	
	5	Does lighting need to be changed so that crossing pedestrians are clearly visible?	N/A	
	6	Is contrast lighting required at the intersection?	✓	The existing 5 m zone, 10-20 km, 10-180 km, not visible
	7	Does the ambient lighting present any special requirements?	N/A	
	8	Can the stationary lighting cause problems in recognizing the traffic signs or the alignment of the road?	N/A	
	9	Are the lighting masts situated outside of the safety zone or properly protected?	X	
	10	Is stationary lighting at intersections/service and rest areas properly situated?	X	Not provided
10. Road side features and passive safety installations	1	Are there any features within the safety zone? 100 km/h ▶ 5 m 80 km/h ▶ 6 m 60 km/h ▶ 3 m	✓	having 2 junctions in 100% T.S.
	2	Are anti-dazzle screens provided as required?	X	
10.1 Other road equipment	3	Has suitable road equipment (fog warning signs, automatic sprinklers for de-icing agents, snow fences etc.) been installed and is it fully functional?	X	
	4	Are there game fences? Is the beginning and end of game fencing correctly determined?	✓	
	5	Is there a mileage system and is it properly signposted?	✓	
10.2 Plantings	1	Is there any vegetation along the road?	✓	
	2	Are there trees?	X	
	3	Are tree trunks free of scars from accidents?	N/A	

Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	4	Does the greenery or will the growth of greenery lead to future safety problems?	X	
	5	Does the greenery and type of planting preclude irritations to the road users (e.g. alignment)?	✓	Monotonous
	6	Is sight obstructed by the planting? Is good visibility ensured at the intersection?	X	
	7	Is visual contact motorist-pedestrian-bicyclist restricted by greenery?	X	
	8	Does vegetation protect the road from natural disasters like land slides etc?	X	
	9	Is the vegetation along the road old and could lead to safety problems?	?	
	10	Does road side vegetation guide the drivers in curves continuously?	X	
	11	Does it obstruct the visibility on the road course (lateral clearance)?	X	
	12	Is the vegetation monotonous? Or does it help to avoid a monotonous character of the road?	✓	Very Monotonous
10.3 Civil engineering structures	1	Is reconducibility from a longer distance guaranteed?	—	
	2	Are passive safety installations set up at the required locations?	—	
	3	Are parapets and overpasses at a safe distance from the road?	—	
	4	Have masts, abutments, supporting walls, bridge railings etc. been safeguarded?	—	
	5	Are there at bridges sufficient passive safety installations, are there properly connected with the guardrails along the road?	—	
	6	Have cyclists' requirements been considered (e.g. separate cycle facilities)?	—	
	7	Is the drainage system a linear obstacle with deep ditches in the safety zone?	—	Drainage only at 110-120km, 140-200km
	8	Are the constructions of culverts obstacle like?	—	
	9	Are there tunnels in the road section?	—	
	10	Are the tunnels safe, are there emergency ways, sufficient illumination etc. (the use the demands of EU - Tunnel directive 2004/54/EC is recommended)?	—	
	11	Is the vertical clearance of under overpasses guaranteed?	—	
10.4 Other obstacles	1	What is the distance of the road directional signing to the pavement?		< 3m
	2	Are the light poles to be considered as an obstacle (steel, concrete construction)?		No signing

Inspection Checklist				
Highway Number ..... from km ..... to km ..... Date:				
Characteristic	No.	Question	Yes (✓) No (X)	Comments
	3	Are there unprotected supports for other cables than lighting in the obstacle-free zone?		
	4	Are traffic signs (other than road directional signs) to be considered as dangerous obstacles?		
	5	Are there unprotected advertisement boards or other fixed obstacles outside the safety zone are they avoidable, or safeguarded?	X	Obstacles too close. Unavoidable in collision
10.5 Passive safety installations	1	Are fixed obstacles avoidable, set up at sufficient distances or safeguarded (masts, abutments, supporting walls, bridge railings, trees etc.)?	X	< 3m <sup>112</sup>
	2	Have passive safety installations been set up at the required locations?		
	3	Are all road safety barriers in place and safely located so that they are not obstacles themselves?	X	< 3m <sup>112</sup>
	4	Is the length of any guardrail adequate?	X	50-100m, 20-201m, 170-190m, 190-200m 100-108m, 170-180m, 160-170m
	5	Is the guardrail correctly installed, regarding: - End treatments, - Anchorage, - Post spacing, - Post depth, - Rail overlap?		
	6	Are dangerous windows of guardrails avoided (comment: windows shorter than 50 m should to be avoided)?		
	7	Are barriers placed so that they don't restrict visibility?		

## **Appendix B**

### **Laingsburg-Beaufort West Single vehicle overturning accidents**

## **Appendix C**

### **Accident types between Laingsburg and Beaufort West**

## **Appendix D**

### **Road Grade**

## **Appendix E**

### **Type of Junction**

## **Appendix F**

### **Obstructions on the road**

## **Appendix G**

### **Condition of the road markings**

## **Appendix H**

### **Type of road markings**

## **Appendix I**

### **Condition of road signs**

## **Appendix J**

### **Presence of road signs**

## **Appendix K**

### **Condition of road surface**

## **Appendix L**

### **Road surface problems**

## **Appendix M**

### **Road surface material**

## **Appendix N**

### **Built up land uses**

## **Appendix O**

### **Road safety audit findings**

## **Appendix P**

### **City of Cape Town fatalities**

## **Appendix Q**

### **City of Cape Town pedestrian fatalities**