Developing a 'Road Safety Desert' Methodology for South Africa

Alexandra Newlands
NWLALE001

Dissertation for the Degree of Master of Science in Civil Engineering at the University of Cape Town, South Africa

Supervisor: Professor Marianne Vanderschuren

February 2023

Plagiarism Declaration

1. I know the meaning of plagiarism and declare that all the work in the document, save for that which is properly acknowledged, is my own. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.

2. I have used the Harvard-UCT convention for citation and referencing. Each contribution to, and quotation in, this body of work, from the work(s) of other people has been attributed and has been cited and referenced.

3. I have not allowed and will not allow anyone to copy my work with the intention of passing it off as his or her own work.

4. I acknowledge that copying someone else's work, or part of it, is wrong, and declare that this is my own work.

5. This thesis/dissertation has been submitted to the Turnitin module and I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor.

Name: Alexandra Newlands

Student number: NWLALE001

Signature: Signed by candidate

Date: 8/02/2023

Cover image obtained from Roadsafety.co.za (2022).

Acknowledgements

The successful completion of this thesis would not have been possible without valuable assistance and support from various individuals. Firstly, I would like to say a massive thank you to my supervisor, Professor Marianne Vanderschuren. Prof, thank you for introducing me to this awesome field of study and for guiding me throughout my journey. You have been such an encouragement to me throughout the last few years, and your passion for the field and the industry as a whole is incredibly inspiring. Thank you, Prof, for always being available whenever I needed guidance in my research, for exposing me to so many amazing opportunities, and for believing in my abilities. It was a privilege to be able to work closely with you.

I would like to thank my fellow student, Bernhard Grosse-Weischede, for providing invaluable support and advice (and snacks!) throughout my master's journey. I would also like to thank Professor Roger Behrens for giving me several awesome opportunities to work on research unrelated to my master's dissertation. These research opportunities broadened my horizons and increased my passion for this field. A further thanks goes to Nicholas Lindenberg from the University of Cape Town's GIS Laboratory for assisting me with my use of GIS software.

Finally, I would like to say a big thank you to my incredible family, in particular my parents, Glynne and Martin Newlands, and my brother, Gryffin Newlands. I would not have been able to successfully complete this degree without your unwavering support, encouragement, and love. Thank you for everything you've taught me.

Soli Deo Gloria.

Alexandra Newlands

Abstract

Road safety is a significant problem in today's world, with the number of fatalities caused by road traffic crashes rising every year. The road safety problem has been described as 'an epidemic on wheels' (Lamont, 2010), which is substantiated by the fact that over 1.35 million people die each year on the world's roads (WHO, 2018a). South Africa's road fatality rate – 21.3 deaths per 100 000 population (RTMC, 2019; STATSSA, 2019) – is considerably higher than the global rate of 18.2 deaths per 100 000 population, and is one of the highest in Africa and the world (WHO, 2018a).

Although South Africa's road fatality rate has continued to decrease over the last decade, the current rate is still unacceptably high. An average of 34 road fatalities occur each day, with 40.5% of all fatalities being some of the most vulnerable road users – pedestrians (RTMC, 2019). Additionally, road crashes cost the country's economy approximately R143 billion in total per year (Labuschagne et al., 2016). Drastic change needs to occur, in order to save the economy billions of Rands, and, more importantly, thousands of lives.

In order to understand and improve the road safety situation of a region and thus decrease the number of road traffic crashes and fatalities, effective road safety assessments must be carried out. While the current road assessment methodologies (e.g., hotspot analyses, fatality rates) provide informative and useful information about the state of road safety in a region, none of them have been able to make a radical difference in solving the road safety problem in the South African context. This indicates that current assessment methodologies are not sufficient for combatting the high fatality rate and do not provide adequate data for tackling this significant problem.

The lack of sufficient road safety assessment methodologies has led to the development of a new road safety assessment approach– namely 'road safety deserts'. This new methodology makes use of the 'desert concept', which is a concept that assesses the equitable distribution of goods and services. In academic literature, a 'desert' is based on a comparison of supply and demand, which was first used to assess access to nutritious food. 'Food deserts' are defined as "those areas of cities where cheap, nutritious food is virtually unobtainable" (Clarke et al., 2002; Whelan et al., 2002; Wrigley et al., 2002). 'Transit deserts' were derived from the 'food

desert' concept and are "areas that lack adequate public transit service given areas containing populations that are deemed transit dependent" (Jiao & Dillivan, 2013).

As the 'food desert' concept was successfully transferred to a different field of study (i.e., transport) (Jiao & Dillivan, 2013), and the 'transit desert' concept was successfully modified to suit the South African context (Vanderschuren et al., 2021), it was concluded that a similar methodology could be developed for the field of road safety.

In the initial stages of developing this new 'road safety desert' methodology, the key data requirements were identified as fatality data, including infrastructure-related data and fatalities per road user type, and road user distribution data, all at the disaggregate Transport Analysis Zone (TAZ) level (sourced from the Integrated Provincial Accident System (2011-1015) and the National Household Travel Survey (NHTS) (2013)). Due to data availability, Cape Town was chosen as the case city where this new methodology could be tested to provide proof of concept.

'Road safety deserts' are defined as areas where there is a significantly higher road safety risk compared to the average road safety risk in the study area. Safety values (using fatalities per road user type) were subtracted from supply quality values (using infrastructure-related attributes) to determine an overall 'safety desert' value for each TAZ. This value represents the road safety risk of an area and can be calculated for different road user types. A positive overall 'safety desert' value indicates that there is a lower road safety risk than the risk for the average person in the study area, and vice versa.

The 'road safety desert' methodology was applied to Cape Town in order to provide a proof of concept. For motorised transport, Kraaifontein and Blue Downs were identified as 'road safety deserts', i.e., having a road safety risk which is significantly higher than the risk to the average Capetonian. On the other hand, Durbanville and Sea Point were found to have a significantly lower road safety risk than the risk in other areas. For non-motorised transport (NMT), Durbanville and Grassy Park were found to be 'road safety deserts'. Belgravia, Central Cape Town, and Simonstown were identified as having a slightly lower road safety risk than the risk to the average Cape Town inhabitant.

The successful 'road safety desert' analysis of Cape Town provides proof of concept for this newly developed methodology. However, during the analysis of the results, a few issues presented themselves, primarily concerned with the data used in this research. The supply quality data should be improved and be specific to the mode being analysed. For example, when analysing NMT 'safety deserts', the infrastructure-related attributes should be NMT specific. Additionally, in areas where a large number of trips are made by non-residents, traffic counts rather than NHTS demand data (which is for residents' trip making only) should be used in the safety value calculation. A further consideration is the use of smaller analysis zones, which would increase the accuracy of the results.

Overall, these results prove that the 'road safety desert' methodology can be applied to a South African city successfully. While several issues did arise in the accuracy of the results, this is not inherently due to problems with the methodology, but due to problems with the data that was available to be conduct this study. It is recommended that other South African and international cities investigate the methodology developed in this study, and use it to identify areas and population groups that carry a high road safety burden. Through this analysis, a road safety strategy can be developed for the areas that need it most.

List of Symbols and Acronyms

BAC	Blood Alcohol Concentration
BRT	Bus Rapid Transit
COVID-19	Coronavirus 2019
DRL	Daytime Running Light
EMS	Emergency Medical Services
FPL	Forensic Pathology Laboratory
GIS	Geographical Information Systems
iPAS	Integrated Provincial Accident System
ITF	International Transport Forum
m	Mode
MBT	Minibus Taxi
MT	Motorised Transport
NHTS	National Household Travel Survey
NMT	Non-Motorised Transport
O	Overall 'Safety Desert' Value
Q	Supply Quality Value
RTA	Road Traffic Accident
RTMC	Road Traffic Management Corporation
S	Safety Value
SPI	Safety Performance Indicator
STATSSA	Statistics South Africa
TAZ	Transport Analysis Zone
UK	United Kingdom
UN	United Nations
US	United States
WHO	World Health Organisation

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Road safety is a significant problem in today's world, with the number of fatalities caused by road traffic crashes rising every year. According to the World Health Organisation (WHO) (2018a), over 1.35 million people die each year on the world's roads, giving credence to the description of the road safety problem as 'an epidemic on wheels' (Lamont, 2010). Globally, the burden of road traffic fatalities lies heavily on children and young adults, with road traffic injuries being the main cause of death for those aged 5-29 years. Additionally, this burden is highly skewed towards low-income countries, where the rate of road traffic fatalities is more than three times greater than that in high-income countries (WHO, 2018a).

Africa's road fatality rate – 26.6 deaths per 100 000 population – is the highest in the world and is considerably higher than the global rate of 18.2 deaths per 100 000 population (WHO, 2018a). Africa only has 2% of the world's registered vehicles, yet its population has the highest risk of dying from road traffic crashes (Peden et al., 2013). This speaks volumes about the dire state of road safety on the continent. Furthermore, vulnerable road users, such as pedestrians and cyclists, bear the brunt of this burden, as 50% of road traffic fatalities occur among these transport modes (WHO, 2016).

Unfortunately, road safety in South Africa is consistent with African trends – in fact, South Africa's road fatality rate is among the worst in Africa and the world. South Africa has a fatality rate of 21.3 deaths per 100 000 population (RTMC, 2019; STATSSA, 2019), and over 12 500 people die every year from road traffic crashes (RMTC, 2019). Following global and African trends, 41% of South Africans who die on the road are under the age of 30, while 38% of road traffic fatalities are pedestrians (many of whom are children) (Verster & Fourie, 2018). These values all point to the need for a radical transformation and improvement of South Africa's road safety, which can only begin once the situation, along with all contributing factors, is thoroughly understood.

In order to understand and improve the road safety situation of a region and thus decrease the number of road traffic crashes and fatalities, effective road safety assessments must be carried out. There are currently many different road safety assessment methodologies in use globally and locally. Prominent assessment methods include the analysis of road safety statistics through absolute and relative fatality rates, as well as before and after studies, road safety audits, hotspot analyses, statistical modelling, and micro-simulation modelling (Mahmud et al., 2019). A number of the abovementioned methods have been applied in South Africa. For example, Vanderschuren et al. (2018) performed a GIS-based identification of hotspots in the Western Cape, resulting in valuable information on the most hazardous locations in the province in terms of road fatalities.

This study explores the possibility of a new road safety assessment methodology, namely 'road safety deserts', which will assess road safety risk related to infrastructure features. This is based on the 'desert' concept (a comparison of supply and demand), which was first used in the United Kingdom to assess access to nutritious food, identifying 'food deserts' – areas that lack access to cheap, healthy food (Clarke et al., 2002; Whelan et al., 2002; Wrigley et al., 2002). 'Food deserts' are often areas where people without private vehicles or those who cannot afford or access public transportation are forced to buy their food at corner shops with limited fresh produce and high prices, rather than more reasonably priced supermarkets with healthier produce located further away (ERS, 2009). The aim of 'food desert' analysis is ultimately to "achieve equitable access to high-quality, affordable food for everyone" (Jiao & Dillivan, 2013:23).

The 'desert' theory was first applied to the field of transport by David Hulchanski, who explored the concept of 'transit deserts' within the city of Toronto (2010). This concept was refined by Jiao et al., who defined 'transit deserts' as "areas that lack adequate public transit service given areas containing populations that are deemed transit dependent" (Jiao & Dillivan, 2013:24; Jiao, 2017). Following this definition, the aim of the 'transit desert' methodology is "to achieve equitable access to high-quality, affordable public transport for everyone" (Newlands, 2020:4). The 'transit desert' theory was then transferred and applied to the South African context by Vanderschuren et al. in 2021, proving that the methodology can be adapted and applied in different contexts.

Success in the application of the 'public transit desert' methodology to South Africa (Cameron, 2019) gives a solid basis for the development of a 'road safety desert' methodology. This will involve modifying and applying the 'desert' concept to the field of road safety. This methodology will add a further analysis dimension to assessing an area's road safety risk, with the hope of using the results to improve the road safety of the area.

1.2 Problem Statement

Although South Africa's road fatality rate has continued to decrease over the last decade, the current rate is unacceptably high. The repercussions of poor road safety have a devastating impact on the individuals involved, namely loss of life or debilitating injury. However, road crashes also place a large burden on the families of those involved, as loss of life or injury of the breadwinner can cause significant financial strain. Apart from the social implications of road crashes, there is also a substantial negative impact on the economy. According to the Road Traffic Management Corporation (RTMC, 2016), each road fatality in South Africa costs approximately R5.4 million, with road crashes costing the economy approximately R143 billion in total per year (Labuschagne et al., 2016). Drastic change needs to occur, in order to save the economy billions of Rands and, more importantly, thousands of lives.

One aspect of combatting high road fatality rates is carrying out effective road safety assessments in order to understand the road safety situation of a region. While the current road assessment methodologies provide informative and useful information about the state of road safety in a region, none of them have been able to make a radical difference in contributing to solving the road safety problem. As mentioned above, several studies have been done on the road safety situation in South Africa using various methodologies. Even though the fatality rate has been slowly decreasing in South Africa, it is still substantially higher than the global average, which points to the fact that current assessment methodologies are not sufficient for combatting the high fatality rate and do not provide adequate data for tackling this significant problem.

Therefore, there is a need for a new methodology to be developed to study this problem – namely 'road safety deserts'. This new methodology will fill a gap in the field of road safety assessment and provide valuable information to government with regard to improving road safety in specific areas. This methodology will identify the areas (using Cape Town as a case study) where there is a high road safety risk compared to other areas, which in turn will inform the implementation of road safety management measures to radically improve road safety in the region.

1.3 Objectives

This study aims to answer the question, "Can the 'desert' concept used in the 'food desert' and 'transit desert' theories be modified and applied to the field of road safety through the creation of a 'road safety desert' methodology?" This question will be answered through the fulfilment of the following research objectives:

- Investigate global and local road safety conditions and fatality rates, as well as methodologies that are used to analyse and assess road safety and road fatalities;
- Examine the 'desert' concept through understanding 'food deserts' and 'transit deserts', including their associated methodologies and applications;
- Transfer the 'desert' concept to the field of road safety through the development of a 'road safety desert' methodology, which will include determining what data will be required as inputs to the methodology;
- Apply this newly developed 'road safety desert' methodology to Cape Town in order to provide proof of concept and identify areas in the city where there is a high road safety risk;
- Assess whether the 'desert' concept was successfully applied to the field of road safety and identify where the methodology can be refined in future applications.

1.4 Scope and Limitations

This study covers the development and application of a 'road safety desert' methodology for South Africa and is primarily intended as a proof of concept for this new assessment methodology. All research is undertaken from home or from the University of Cape Town's Upper Campus, adhering to all COVID-19 regulations. Road safety data and geospatial data used in this study are limited to what data has been collected by and is available from organisations and/or government. These data limitations affect the following aspects of this study:

- Large analysis zones are used in the application of this methodology to the City of Cape Town. This results in somewhat cruder results, but still allows for the validity of the methodology to be tested and proven.
- While analysis of individual modes would be ideal, this analysis is done on the broad grouping of motorised transport and non-motorised transport modes only.

In this study, the ‘road safety desert’ methodology is only applied to Cape Town. However, it is assumed that this methodology is replicable in other South African cities. The methodology developed in this research only considers road fatalities and not road crashes or injuries, and will only consider road/environment contributory factors in its calculations.

1.5 Content

Following this introductory chapter, this dissertation consists of six main chapters. Chapter 2 reviews literature on road safety assessment methodologies both globally and locally, while Chapter 3 describes the road safety status quo on a global, African, and South African scale. The following chapter, Chapter 4, outlines the methodology and research approach used in this study, including literature on the ‘desert’ theory, focusing on ‘food deserts’ and ‘transit deserts’. This chapter also, importantly, details the development of the ‘road safety desert’ methodology. Chapter 5 presents the results of the ‘road safety desert’ methodology’s application to the City of Cape Town, and analyses and discusses these findings. Finally, Chapter 6 draws conclusions from this study and puts forward recommendations for further research.

2. Road Safety Assessment Methodologies

2.1 Introduction

In order to improve the road safety of a region by implementing appropriate road safety measures, the state of road safety in this region needs to be known and understood first. This information is obtained through the use of road safety assessment methodologies. As said by British scientist Lord Kelvin, *"If you cannot measure it, you cannot improve it",* which is apt when describing the aim of road safety assessment methodologies. Their purpose is to gather meaningful information about the road safety status quo of an area, to enable comparisons between areas, to enable the monitoring of road safety progress and targets over various periods, and to use this information to identify appropriate road safety interventions (Gitelman et al., 2010).

This chapter will investigate various road safety assessment methodologies. Firstly, a background to the road safety management system will be given, including a brief discussion of background characteristics and safety performance indicators. This will be followed by detailed reviews of two common assessment methodologies, namely hotspot analysis and fatality rates. Other assessment methodologies will also be touched on, including traditional and emerging methods. Finally, a summary and conclusion of the chapter will be given.

2.2 Road Safety Management Systems

Road safety assessment methodologies play a crucial role in road safety management systems, as they are the means by which the road safety situation of a region is understood. Figure 2.1 presents a road safety system hierarchy, which shows the various components used to evaluate road safety in an area, including the role of assessment methodologies in the system (Koornstra et al., 2002; LTSA, 2000).

The bottom tier of the hierarchy investigates the structure and culture of a region (i.e., background characteristics), while the second tier involves the implementation of specific road safety measures and programmes. The third tier uses safety performance indicators (SPIs) (intermediate outcomes of the road safety system) to assess the operational conditions of the road system (see Section 2.2.1), and the fourth tier looks at the number of fatalities and injuries (see Sections 2.4 and 2.5). The number of fatalities and injuries are the final outcomes of the road safety system, obtained using road safety assessment methodologies. The final tier, social costs, refers to the impact of the previous tier – fatalities and injuries – on society as a whole.

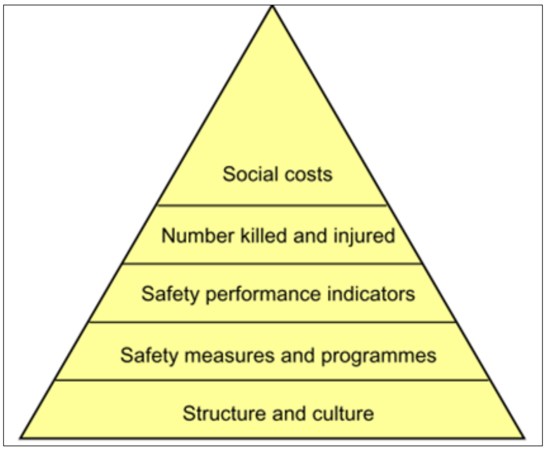


Figure 2.1: Road safety hierarchy (Koornstra et al., 2002)

Figure 2.2 shows how the components of Figure 2.1 fit together in more detail. The operational conditions of road traffic, measured by SPIs, are directly affected by outputs of safety measures/programmes. For example, in the case of speeding, the safety measure introduced could be speed enforcement. The output of this would be the use of physical speed cameras to reduce speeding and improve the operational conditions on the road. This improvement would be measured by the SPI level of speeding (e.g., % speed limit offenders). The improved operating conditions would lead to a reduction in crashes, fatalities, and injuries (measured by road safety assessment methodologies), which would reduce the overall cost to society (Hakkert et al., 2007).

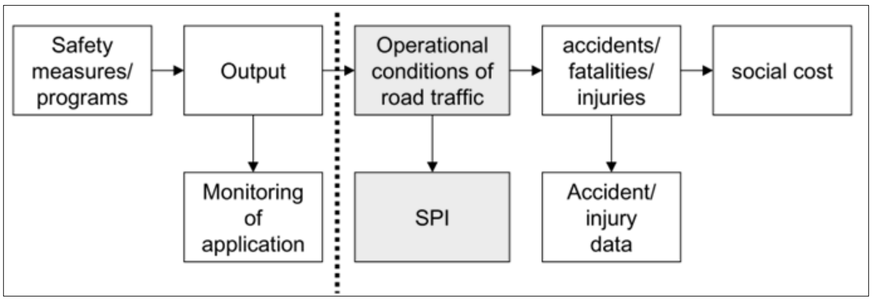


Figure 2.2: Road safety management system (Hakkert et al., 2007)

As shown in the bottom tier of the hierarchy in Figure 2.1, background characteristics that give insight into the structural and cultural context of a region are important in understanding the setting in which the road safety management system is located. These characteristics also provide insight into the reason behind the road safety status quo of an area. Examples of background characteristics include motorisation level, urbanisation level, population demographics such as age and gender, population density, and socioeconomic status. These are all factors that influence road safety, albeit indirectly. For example, regions with a low average income per capita (low-income countries) generally have a much higher fatality rate for pedestrians and cyclists, as road users cannot afford other means of transport (Gitelman et al., 2010).

It is important to note that while the above figure is useful for displaying the components of a road safety management system, feedback loops between monitoring, SPIs, and accident/injury data, which are crucial parts of the system, are not shown in this diagram. These feedback loops should always be included when considering the road safety management system as a whole.

2.2.1 Safety Performance Indicators

The final outcome of a road safety management system is the number of crashes, fatalities, and injuries that occur in an area. These are, of course, essential values to know in order to understand and improve the road safety of an area. However, these numbers do not necessarily offer any information into the processes that caused them (Gitelman et al., 2014). This need for more detailed information about road safety conditions led to the development of safety performance indicators (SPIs), also known as intermediate outcomes in the road safety management system.

Safety performance indicators are defined as “measures reflecting the operational conditions of the road traffic system that influence the system’s safety performance” (Gitelman et al., 2014). They are indicators which measure factors or activities that are causally related to crashes, giving a more comprehensive picture of the road safety situation, and providing a link between the repercussions of crashes and the measures that could reduce them (ETSC, 2001; Hakkert et al., 2007).

SPIs enable a deeper understanding of the final outcomes, and reveal the factors and events that produce fatalities, injuries, and crashes. They are also useful for monitoring the impact of road safety measures and road safety performance, defining and creating trends, foreseeing potential problems, and comparing road traffic systems in different areas (Davidovic et al., 2020; Gitelman et al., 2014). There are several main safety areas that have associated SPI's, including alcohol and drugs, use of protective systems, use of daytime running lights, speed, vehicles (also referred to as passive safety), roads, and trauma management (Gitelman et al., 2014). Table 2.1 shows a non-exhaustive list of these safety areas and their associated SPIs.

Table 2.1: Selection of several safety performance indicators (Gitelman et al., 2014; Hakkert et al., 2007; Vis, 2005; Holló et al., 2010; Hermans et al., 2008; Tešić et al., 2018)

SAFETY AREA	INDICATOR
Alcohol and drugs	% Drivers above the legal BAC limit
	% Drivers under the influence of drugs
Use of protective systems	Wearing rates of safety helmets by cyclists and two-wheeler drivers
	Wearing rate of seatbelts in front seats (passenger cars/vans, heavy goods vehicles, buses), rear seats, and by children under 12 years old
Use of daytime running lights (DRLs)	DRL usage rate in total, per road type, and per vehicle type
Speed	Mean speed
	% Speed limit offenders by road type, vehicle type, and time of day
	85^{th} Percentile speed
Vehicles	Vehicle fleet composition: % heavy goods vehicles and % motorised two-wheelers
	Crashworthiness: median age of passenger car fleet
Roads	Road network: % of appropriate actual road category length per theoretical road category
	Road design: road protection scores per category
Continued on following page…	

Trauma management	Number of emergency medical service (EMS) stations per 10 000 population and per 100km of rural public road
	Number of EMS transport units per 10 000 population and per 100km of total road length
	Average EMS response time
	% EMS responses meeting the demand
	% Basic life support units, mobile intensive care units, and helicopters/planes out of total EMS transportation units
	Total number of trauma care beds per 10 000 population

While SPIs play a vital role in the road safety management system, the final outcomes (i.e., number of crashes, fatalities, and injuries) are most important. Two of the main road safety assessment methodologies that provide information about final outcomes – hotspot analysis and fatality rates – will now be discussed in detail.

2.3 Hotspot Analysis

A hotspot (or black spot) is a "location that has a higher expected number of crashes than similar locations, as a result of local risk factors" (Ross et al., 2015:7). Hotspots can be found at intersections, mid-block locations, or along a short or long section of road (Meuleners et al., 2018).

Hotspot analysis is an approach to road safety assessment that identifies hazardous locations and enables targeted infrastructure implementations (e.g., improved road design, introduction of roundabouts or traffic signals etc.) to be carried out to improve the safety of each location (Shafabakhsh et al., 2017). It is widely accepted that the identification, analysis, and treatment of hotspots is an effective way to reduce road traffic crashes (Elvik, 1997; Levine, 2006). For example, a hotspot programme in Australia managed to reduce all crashes at identified hotspots by 14% through implementing road safety interventions (Meuleners et al., 2008).

The classification of hotspots differs internationally. Literature shows that hotspots can be identified by the absolute number of crashes or fatalities, crash or fatality rate, crash or fatality frequency, intensity of crashes, and/or estimated future crashes (Colak et al., 2018; Fawcett et al., 2016; Hauer, 1996; Zahran et al., 2021). Detailed definitions of hotspots also differ between countries, for example:

- Norway: a hotspot is any location, 100m long, where a minimum of four crashes resulting in injuries have occurred during the past five years (Elvik, 2008);
- Switzerland: a hotspot on a motorway is any site (up to 500m long) that has recorded a minimum of 10 crashes, four injuries, and two fatalities within the last two years (Elvik, 2008);
- Turkey: a hotspot is a location where four or more crashes occur in one year (Erdogan et al., 2008);
- England: an area is a hotspot if 20 or more crashes were recorded over three years on a 100m length of road (Gregory & Jarret, 1994).

These international definitions cannot be directly transferred to the South African context, as the state of road safety in South Africa is much worse. For example, Vanderschuren et al. (2017a) found one location in Cape Town where an average of 618 crashes occurred within a $100m^2$ area in one year, which is significantly higher than the minimum amount of crashes specified in the definitions above. Additionally, it is acceptable in the South African context to only identify hotspots via fatalities (as long as other crash information is also assessed), as the road safety problem is more severe in this country (Vanderschuren et al., 2017b). Internationally, countries that experiences low fatality numbers use a weighted sum of fatalities, injuries, and damage-only crashes (Elvik, 2007).

The two case studies below further illustrate the different approaches to identifying hotspots.

2.3.1 Case Study: Jalan Tutong Road, Brunei

Brunei is a small country with a low population count and is located on the north coast of the island of Borneo in Southeast Asia. Most trips (98%) in Brunei are private cars, with a small amount of motorcycle, bicycle, and pedestrian trips. In 2021, a hotspot analysis was conducted on a 4.1km long section of the Jalan Tutong Road, an important road located in the north of the country (Zahran et al., 2021).

Hotspots were identified using the spatial traffic accident analysis method (STAA), which uses geo-coded crash, fatality, and injury data. This method accounts for crash frequency and severity. There were 223 road traffic crash points along the section of road in question. Using a Geographical Information System (GIS), these points were converted into 223 overlapping polygons with a buffer radius of 78m (the stopping sight distance calculated for this section of road). Polygons that overlapped were merged together, resulting in eight distinct hotspot polygons (Figure 2.3). The 'join' tool in ArcGIS was then used to consolidate the point crash data into the polygons so that each hotspot polygon reflected the sum of fatality, serious injury, minor injury, and no injury cases (Zahran et al., 2021).

Figure 2.3: Road traffic accident (RTA) hotspots along Jalan Tutong Road (Zahran et al., 2021)

In order to evaluate the road safety risk of each polygon, a 4 x 4 matrix comparing normalised frequency (NF) and normalised severity (NS) was established (Figure 2.4). These parameters were calculated using the following equations (Zahran et al., 2021):

$$NF = RTA \times \frac{SSD}{L} \times \frac{1}{N} \quad (1)$$

$$NS = S \times \frac{SSD}{L} \times \frac{1}{N} \quad (2)$$

Where:

NF = average annual number of road traffic accidents (RTA) within each hotspot zone per SSD

RTA = RTA count within each hotspot zone

SSD = stopping sight distance (m)

L = length of hotspot zone along the road centreline (m)

N = number of years of data

NS = normalised severity (S per SSD length per year)

$$S = \text{severity} = X + 3Y + 5Z \qquad (3)$$

Where:

X = total number of minor injuries within each hotspot zone per SSD

Y = total number of major injuries within each hotspot zone per SSD

Z = total number of fatalities within each hotspot zone per SSD

The severity weighting used in Equation 3 is based on the weighting system used by the Belgium government to detect hotspots. While there are several different weighting systems in use globally, this one was found to be the most accurate in predicting hazardous locations in this study (Zahran et al., 2021).

Finally, new fields in the attribute table in GIS for the NF and NS values were added for each polygon. Each hotspot polygon was assigned a composite risk level determined by a 4 x 4 matrix of NF versus NS, ranging from minor (green) to serious (black). For example, if a hotspot polygon had a NF value greater than the 75th percentile and a NS value between the 25th and 50th percentile, the composite risk level would be significant (red) (Figure 2.4). The result of this analysis is shown in Figure 2.5.

Matrix (a)		NF			
		NF > 75th Percentile	50th Percentile < NF ≤ 75th Percentile	25th Percentile < NF ≤ 50th Percentile	0 ≤ NF ≤ 25th Percentile
Normalised severity (NS)	NS > 75th Percentile	Serious	Serious	Significant	Moderate
	50th Percentile < NS ≤ 75th Percentile	Serious	Significant	Moderate	Moderate
	25th Percentile < NS ≤ 50th Percentile	Significant	Moderate	Minor	Minor
	NS = 0	Moderate	Minor	Minor	Minor

Figure 2.4: Composite risk levels based on normalised frequency and normalised severity (Zahran et al., 2021)

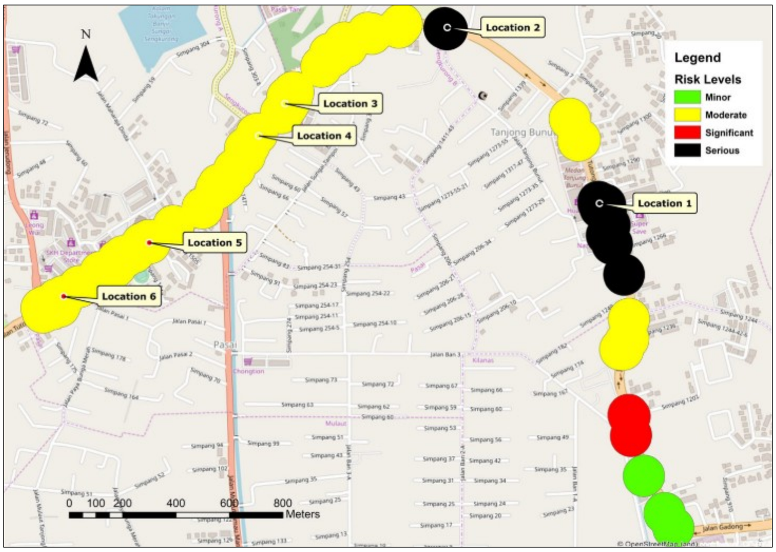


Figure 2.5: Risk levels of hotspots along Jalan Tutong Road (Zahran et al., 2021)

It can be seen that the majority of hotspots are of moderate risk, while there are several of serious risk and a few of significant and minor risk. This hotspot assessment methodology was found to be useful for urban arterials and high-density junctions. A further advantage of this methodology is that it can also be used to determine the socio-economic risk of hotspots, which will enable a more holistic identification of hotspots (Zahran et al., 2021).

2.3.2 Case Study: West Coast, South Africa

In 2017, a hotspot analysis was conducted for the West Coast region in the Western Cape province, South Africa. This province is in the south-western corner of the country, and the West Coast region, a relatively sparsely populated area, is located in the north-west of the province.

Geo-coded fatality data from the Integrated Provincial Accident System (iPAS) was used in this analysis. The ‘fishnet’ tool in GIS clustered fatalities that occurred at the same location, i.e., hazardous locations or hotspots. The area size used was 100m by 100m, in accordance with international best practice (Vanderschuren et al., 2017b; Elvik, 2007). This was verified for the South African context via Google Earth: a typical South African intersection size was found to be approximately 100m^2. This area size reduces the chance of links in the road network being included/combined with the intersection area. As crossing traffic represents conflicts that could potentially lead to road crashes and fatalities, the authors wanted to ensure that intersections could be identified (Vanderschuren et al., 2017a).

Fatality locations were plotted on a map of the West Coast (Figure 2.6) and a preliminary analysis of this map found that many fatalities occurred in the same location. It is important to note that the City of Cape Town questioned the accuracy of the location data. The authors are not in a position to verify the accuracy. The authors (Vanderschuren et al., 2017b) recommended that the accuracy of geo-location data be improved for practical application in South Africa.

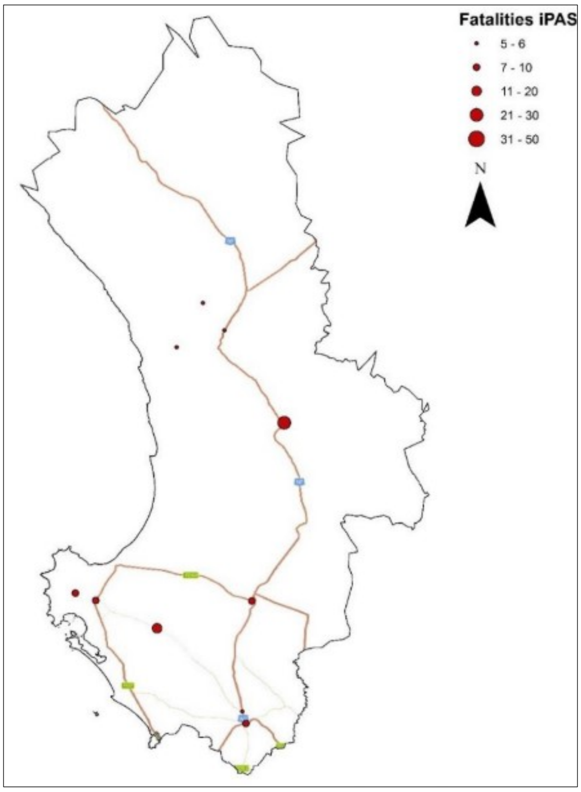


Figure 2.6: Top ten hazardous locations in the West Coast region (Vanderschuren et al., 2017b, based on iPAS 2011-2015 data)

The location in the West Coast region with the highest number of fatalities was the intersection between the R364 and Hoof Street in Clanwilliam, with an annual average of 21 fatalities occurring in the five-year period. Additionally, 150 crashes and 113 injuries occurred at this location (Vanderschuren et al., 2017b). These fatality and crash numbers clearly show that intervention is needed at this location. Once identified, a visual review of the location was conducted using Google Street View and countermeasures were proposed. Potential remedial actions recommended include the following road safety warrants:

- Delineation and signage to indicate the curve in the road;
- Reduction in speed through lowering the speed limit and introducing traffic-calming measures;
- Rumble strips at the approach to the town to indicate an urban area and speed reduction;
- Variable message signs at the entrance to the town to indicate an urban area and speed reduction (Vanderschuren et al., 2017b).

2.4 Fatality Rates

Absolute fatality numbers, while being useful for locating hotspots and implementing targeted interventions, do not allow for accurate comparisons of road safety across regions with different populations (human and vehicular). In order to meaningfully compare different regions or countries, fatality rates, as defined by the World Health Organisation (WHO), are used as assessment methodologies.

The most commonly used fatality rate converts the absolute number of road fatalities into road fatalities per 100 000 population (WHO, 2013; Kukić et al., 2016), which standardises fatalities by the population of the region and allows for the aforementioned comparison to occur. Injuries and crashes per 100 000 population are two other useful rates that indicate the risk of being injured in a crash or being involved in a crash. Babanoski, Ilijevski, & Dimovski (2016) classified these three rates as 'public risk' indicators, as they make use of population counts and indicate the road safety risk to the general population (the public).

'Public risk' indicators, however, do not take into consideration the degree of motorisation in the region. 'Dynamic traffic risk', i.e., fatalities per 100 million passenger-km travelled, does take motorisation and the mobility of the population into account and is the best measure of risk of death when travelling by car. Unfortunately, many countries do not record data about passenger-km travelled, and so the more common 'traffic risk' indicator is used, namely fatalities per 10 000 registered vehicles. This fatality rate also considers motorisation and measures the risk of dying in a crash (Babanoski, Ilijevski, & Dimovski, 2016; Kukić et al., 2016; Wegman & Oppe, 2010).

Fatality rates can also be used to compare fatalities by mode, gender, income, and road category, e.g., pedestrian fatalities per 100 000 population (Kukić et al., 2016). Displaying fatality rates per geographical area is also useful, as it brings a social justice component into the road safety assessment (see Figure 2.7 below).

While fatality rates are an extremely valuable assessment methodology, they are an imperfect way of assessing road safety, as they do not provide insight into the underlying processes that caused the crashes in the first place (Gitelman et al., 2013). Further problems with these indicators are that the reporting of fatalities, injuries, and crashes is often incomplete or inaccurate, and that the number of fatalities, injuries, and crashes can fluctuate in the short term, something that is not well-reflected in these long-term indicators/rates (Hakkert et al., 2007).

In addition, the definition of a fatality differs between regions. Road fatality rates per 100 000 population is commonly used by the WHO, who define a road traffic fatality as "any person killed immediately or dying within 30 days as a result of a road traffic accident" (WHO, 2013). While this definition is used in many countries around the world, the total number of fatalities recorded may not be completely aligned with this definition, especially in developing countries. This is partly, due to the fact that fatalities that occur days after a road traffic accident (and not immediately at the scene of the crash) are often not recorded as a road traffic fatality, due to poor feedback processes between the police and hospitals.

A brief case study will now aim to show how fatality rates can be used to assess the road safety of multiple regions per road user. Chapter 3 provides more examples of the use of fatality rates.

2.4.1 Case Study: Western Cape, South Africa

The same study done by Vanderschuren et al. (2017b), previously described in Section 2.3.2, determined the average annual fatalities per 100 000 population per road user for areas within the Western Cape province. The modes considered were cyclists, pedestrians, motorcyclists, drivers, and passengers.

The result of this analysis is shown in Figure 2.7, where a larger pie chart size indicates a higher fatality rate per 100 000 population (Vanderschuren et al., 2017a). The areas with the highest road safety risk (i.e., higher fatality rates) were Laingsburg, Cederberg, and Prince Albert respectively, with passenger fatalities per 100 000 population making up the highest portion of fatalities for all three. Cape Agulhus, Bergrivier, and Cape Town have the lowest fatality rate in the Western Cape.

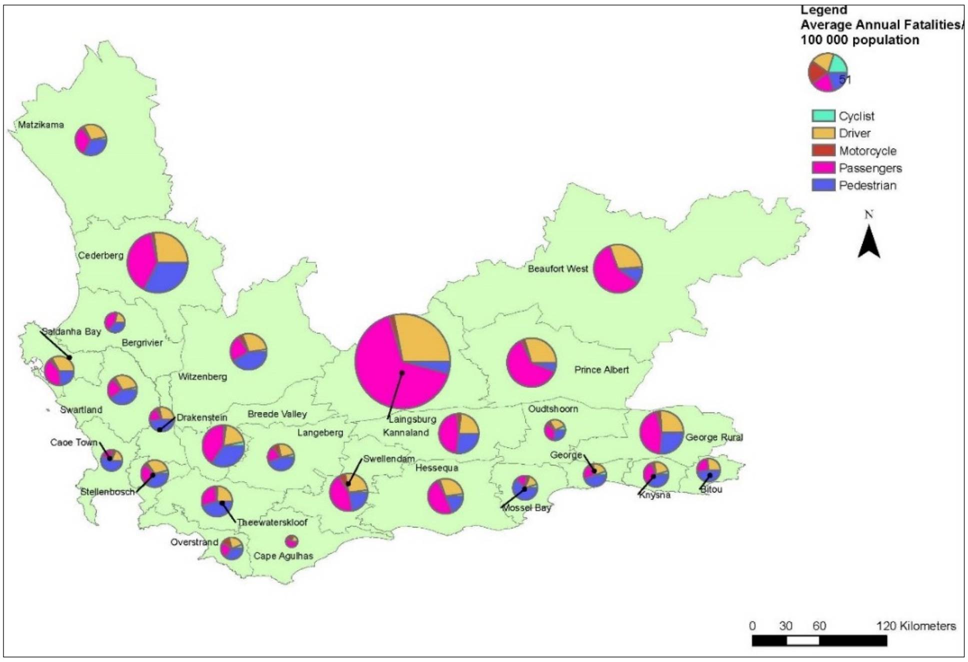


Figure 2.7: Average annual fatalities per 100 000 population per mode for different areas in the Western Cape (Vanderschuren et al., 2017a, based on NHTS 2013 and FPL 2011-2015 data)

An interesting finding of the study was the significant differences between absolute fatalities per area compared to the fatality rates per 100 000 population. This is shown in Table 2.2. As mentioned, the areas with the highest fatality risk per 100 000 population were Laingsburg, Cederberg, and Prince Albert. However, the top three worst areas with respect to absolute fatalities were three different areas, namely Cape Town (50% of all fatalities in the province), Breede Valley, and Witzenberg (Vanderschuren et al., 2017a). It is clear that the areas that need intervention, based on fatality rates, greatly differ from those that need intervention based on absolute numbers. This shows that it is important to not only consider fatality rates or absolute fatalities by themselves, but also that they should be considered together.

Table 2.2: Top three worst locations for road safety based on absolute fatalities and fatalities per 100 000 population

FATALITIES PER 100 000 POPULATION	ABSOLUTE FATALITIES
1. Laingsburg	1. Cape Town
2. Cederberg	2. Breede Valley
3. Prince Albert	3. Witzenberg

2.5 Other Road Safety Assessment Methodologies

2.5.1 Traditional Assessment Methodologies

Traditional road safety assessment methodologies are largely based on historical crash records, statistical modelling, or professional field observations. The purpose of these assessments are to develop a thorough understanding of the site's crash and fatality patterns, safety concerns, and the causes of crashes, in order to choose the correct countermeasures (AASHTO, 2009). These include hotspot analysis and fatality rates (as described above), before and after studies, statistical modelling, and road safety audits (Mahmud et al., 2019). However, these methods are not always suitable and have several potential problems that need to be kept in mind, including:

- Poor crash reporting and recording;
- Reliance on professional judgement;
- Reliance on the accumulation of large amounts of crash data before any countermeasures can be implemented;
- Failure to give a complete understanding of the processes leading up to crashes;
- Failure to give reasons why countermeasures are successful or unsuccessful (Mahmud et al., 2019).

Nevertheless, the methods above provide valuable information and are still widely used. A good example of a traditional road safety assessment method is given in detail in the *Highway Safety Manual – 1st Edition*. This method has three distinct steps, the first being a thorough review of safety data, such as crash types and locations. The second step involves an assessment of supporting documentation including past studies and known issues, while the third step involves the assessment of field conditions. This a comprehensive methodology that has, generally, resulted in appropriate countermeasures being selected (AASHTO, 2009).

Further assessment methods are described in detail by Marta et al. (2011), and can be seen in Table 2.3. Each method results in a different level of detail depending on the situation and the analysis site (e.g., road network, routes/towns, or road/site). Their aims are to reduce the number of road crashes and reduce the negative impact of those crashes.

Table 2.3: Traditional road safety assessment methods (Marta et al., 2011:2)

METHOD	DESCRIPTION
Network risk assessment	An assessment of road safety risks across a defined road network to identify general areas of risk in road safety. Considers network operations, road characteristics, and crash history.
Major project safety assessment	A review of road safety along a proposed road project to identify road safety issues and areas of risk that could lead to road crashes or harm to people, and establish approaches or actions to enhance road safety benefits.
Road safety evaluation	An examination of the potential and actual road safety risks for an existing road to identify road safety issues and risks that have or could lead to road crashes or harm to people. Includes a road safety audit, crash investigation, and speed zone review.
Road safety audit	An examination of road safety risks along a future or existing road to identify road safety issues and risks that could lead to road crashes or harm to people. Considers road and traffic characteristics and design plans, and is most effective before a road is built.
Crash investigation	A detailed analysis of road crashes over a number of years along an existing road. The aim is to identify and analyse crash clusters, fatal and injury crash sites, common crash characteristics and types, and develop appropriate treatments.
Continued on following page…	

Speed zone review	An assessment of speed limits along an existing road to provide an appropriate level of safety while allowing for mobility and amenity on public roads. Considers the road function, roadside development, and road and traffic characteristics.
Safety benefits and impacts calculation	An assessment of the impact on road safety of proposed work on an existing road to identify treatments for specific works, which offer the highest benefit for road safety, and to compare the impact on road safety of each proposed work to assist in prioritising a programme of works. Considers crash history and treatment options.

2.5.2 Emerging Assessment Methodologies

Recent years have seen the emergence of several new road safety assessment methodologies that provide different perspectives on road safety problems by using different technology, data sources, and/or methods.

A significant example of these newer methods is micro-simulation modelling. According to Jobanputra (2013:i), micro-simulation modelling to can be used "to provide a better understanding of the interaction between the road-user and the infrastructure, and to evaluate the benefits of engineering countermeasures and provide a comparative safety evaluation of urban infrastructure with different operational characteristics." These simulations allow for the assessment of road safety without the need for crash data, which is an important difference when compared to traditional methods. These models result in predictions of speed, flow, headways, and gap-acceptance, while additionally allowing for sensitivity analysis of countermeasures without any implementation (Jobanputra, 2013). Numerous micro-simulation models have been produced for different situations, e.g., analysis of conflict points in roundabouts. There is still a substantial amount of work to be done in developing this assessment method, but it promises to be an important tool in the future (Mahmud et al., 2019).

The use of smartphone-based measurement systems using co-operative intelligent transport system (C-ITS) is another up-and-coming methodology. These systems aim to improve road safety by new intelligent systems in vehicles connected to GPS-enabled smartphones. Detailed information about the drivers' driving style and statistics about their trips are sent to operators who are then able to analyse the whole database and identify hazardous points in the network where frequent unsafe driver behaviour occurs. This system also provides information about the safety of vehicles, road conditions and infrastructure, which allows for appropriate countermeasures to be implemented (Astarita et al., 2014).

2.5.2.1 Fatalities per Mode Share

Another new assessment methodology is assessing the state of road safety in an area using fatalities per mode share. In the aforementioned study conducted in the Western Cape, South Africa, Vanderschuren et al. (2017a) combined the analysis of mode distribution per Transport Analysis Zone (TAZ) and fatalities to calculate fatalities per mode share. Fatality rates (per mode) cannot be expected to be homogeneous across a TAZ or road category. For example, in the European context, where conducive secondary and tertiary road networks are available, pedestrian fatalities on freeways hardly occur. This is because the mode (pedestrian) is absent in this environment. Based on this insight, it is likely that road fatalities are related to the mode share in an area.

The percentage difference between mode distribution and absolute fatalities is used in order to determine whether the mode is over- or under-represented in the number of fatalities. The percentage mode share is subtracted from the percentage of fatalities for that mode to generate a delta value. In this method, “a positive difference indicates that the percentage death toll for the road user type is higher (unwanted) when compared to the percentage of the population that utilises that particular mode, for their daily trips and vice versa” (Vanderschuren et al., 2017a:18).

Figure 2.8 displays the results of the aforementioned study for pedestrians, and shows that the average annual number of fatalities and the mode share for the Western Cape is almost identical. Some areas, however, have numbers of average annual pedestrian fatalities much higher than the mode share. For example, Belgravia has over 50% more pedestrian fatalities than its mode share, which is a cause for concern. Additionally, Sea Point, Durbanville, and Grassy Park have pedestrian fatalities significantly greater than their mode share. On the other hand, Laingsburg (70%), Cape Agulhas (64%), and Prince Albert (58%) have average annual pedestrian fatality numbers lower than the mode share, which is encouraging to see (Vanderschuren et al., 2017a).

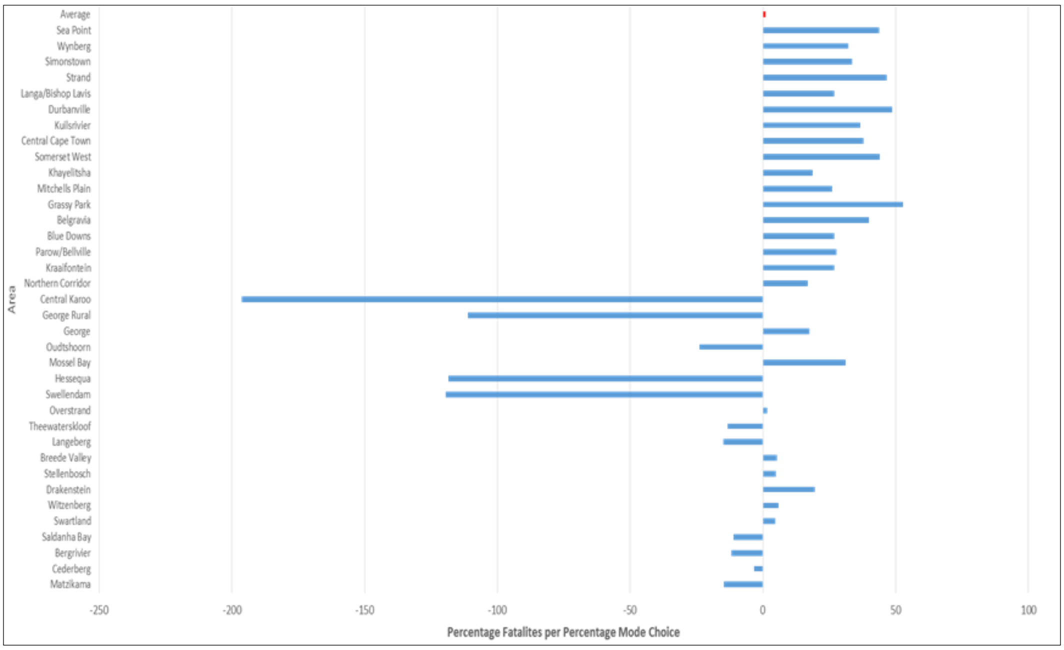


Figure 2.8: Percentage average annual pedestrian fatalities per percentage pedestrian mode share for the Western Cape (Vanderschuren et al., 2017a, based on NHTS 2013 and FPL 2011–2015 data)

Fatalities per mode share is not a common assessment methodology, and although already applied in 2017, has not been adopted internationally yet. If applied per location (TAZ), fatalities per mode provide a social justice aspect to the road safety assessment, as it is possible to identify which areas are safer than others. This assessment methodology is useful in determining where road safety problems exist (i.e., areas with a positive difference) for different mode shares, and its use should be considered when performing road safety assessments.

2.6 Résumé

This chapter set out to investigate various road safety assessment methodologies, which are crucial tools in measuring and understanding the road safety status quo of an area and identifying appropriate road safety interventions.

Firstly, a brief review of the road safety management system was done. This included a description of the road safety hierarchy, background characteristics, and SPIs. The road safety hierarchy consists of structure and culture, safety measures and programmes, SPIs, number killed and injured, and social costs. Background characteristics form the base of the system and provide information about the structural and cultural context of the location being assessed. SPIs form an important part of the hierarchy as intermediate outcomes of road safety, and measure the operational conditions of the road that influence safety (Koornstra et al., 2002; LTSA, 2000).

The number of fatalities and injuries in road crashes are the final outcomes of the road safety management system and are assessed using road safety assessment methodologies (Koornstra et al., 2002). Two of these methodologies were discussed in detail, namely hotspot analysis and fatality rates. The identification, analysis, and treatment of hotspots is an effective way to reduce road traffic crashes. Hotspot analysis identifies hazardous locations and enables targeted infrastructure implementations to be carried out to improve the safety of each location (Shafabakhsh et al., 2017). Different definitions of hotspots were discussed, and two examples of hotspot analyses were given.

Absolute fatality numbers, while useful for locating hotspots and implementing targeted interventions, do not allow for accurate comparisons of road safety across regions with different populations. In order to meaningfully compare different regions or countries, fatality rates are used as assessment methodologies. The most commonly used fatality rate is road fatalities per 100 000 population, especially by the health science fraternity (WHO, 2013; Kukić et al., 2016). Other important rates include fatalities per 100 million passenger-km and fatalities per 10 000 registered vehicles. A brief case study of the Western Cape was done in order to demonstrate the importance of this assessment methodology.

Finally, other road safety assessment methodologies were discussed. Other traditional methodologies, such as road safety audits and network risk assessments, were briefly covered, and the pros and cons of traditional methodologies discussed (Mahmud et al., 2019; Marta et al., 2011). Emerging methodologies, including micro-simulation modelling, smartphone-based measurement systems, and fatalities per mode share were reviewed (Jobanputra, 2013; Mahmud et al., 2019; Astarita et al., 2014). In the fatalities per mode share methodology, the percentage difference between mode distribution and absolute fatalities is used in order to determine whether the mode is over- or under-represented in the number of fatalities (Vanderschuren et al., 2017a).

Overall, this chapter has shown that there are many different road safety assessment methodologies that can be used to analyse and understand the road safety status quo of an area, all with pros and cons. However, as will be seen in the following chapter, while the current road assessment methodologies provide informative and useful information about the state of road safety in a region, none of them have been able to make a radical difference in solving the road safety problem. Therefore, to study this problem further, a new methodology needs to be developed.

3. Road Safety Status Quo

3.1 Introduction

The current state of road safety around the world is nothing less than a global health crisis, aptly termed by Lamont (2010) as an 'epidemic on wheels'. In 2018, the World Health Organisation (WHO) published the *Global Status Report on Road Safety 2018,* which thoroughly investigated the state of road safety around the world. This report confirmed that road traffic fatalities and injuries are a health crisis, as it was found that they are the leading cause of death for those aged 5-29 and the eighth leading cause of death for all ages (WHO, 2018b). The fact that children and young adults are most likely to die or be seriously injured on the road is shocking, and should spur us on to drastically reduce the number of road fatalities and injuries around the world.

A first step in working towards improving road safety in any area is understanding the road safety status quo of that area (i.e., what the current road fatality and injury trends are). This chapter will investigate the state of road safety on a global scale, including road fatality and injury trends and causes in regions around the world. The road safety status quo in Africa will then be discussed, followed by a detailed investigation of road safety in the South African context. These findings will then be summarised, and next steps proposed.

3.2 Global Status Quo

While Lamont described road fatalities as an epidemic in 2010, the British Medical Journal (BMJ) had already described road fatalities as a pandemic three decades earlier (BMJ, 1973). This description is corroborated by the fact that since the invention of the automobile, more than 50 million people around the world have died due to road traffic crashes (WHO, 2022). Approximately 1.35 million road traffic fatalities occur on the world's roads each year, which equates to nearly 3 700 people dying from road traffic crashes every day and more than two every minute (WHO, 2018; WHO, 2022).

Although these figures are unacceptably high and the absolute numbers are continuing to increase, the annual fatality rate relative to the world's population size (fatality rate per 100 000 population) has stabilised at approximately 18 fatalities per 100 000 population (Figure 3.1)

(WHO, 2018). Even though this suggests that the road safety problem is not worsening, fatality rates are still unacceptably high, and the number of road fatalities are far from being halved by 2030 – the goal of the United Nation's Second Decade of Action.

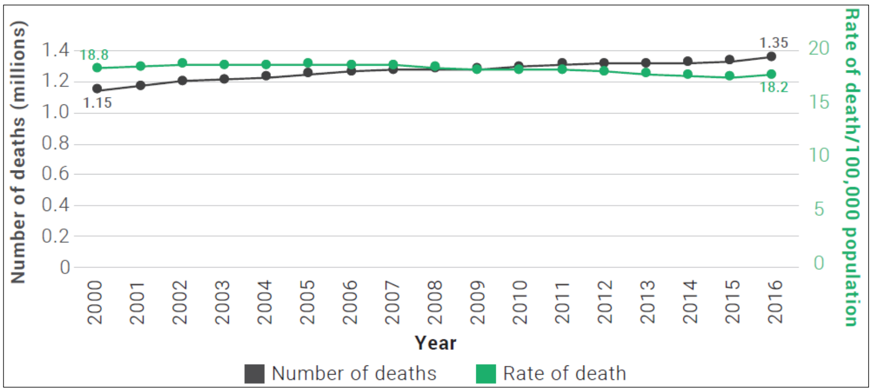


Figure 3.1: Global fatality numbers and fatality rates per 100 000 population from 2000-2016 (WHO, 2018)

While the number of vehicles globally continues to increase, the fatality rate relative to the number of motor vehicles has declined significantly. In 2000, the fatality rate was 135 fatalities per 100 000 vehicles, and in 2016, this had decreased by over 50% to 64 fatalities per 100 000 vehicles (Figure 3.2). This progress is encouraging and shows some success in efforts to reduce the negative impacts of increased motorisation. However, the fatality rate per 100 000 vehicles is still extremely high, which shows that this progress has not occurred fast enough to compensate for rapid population growth and increased motorisation (WHO, 2018).

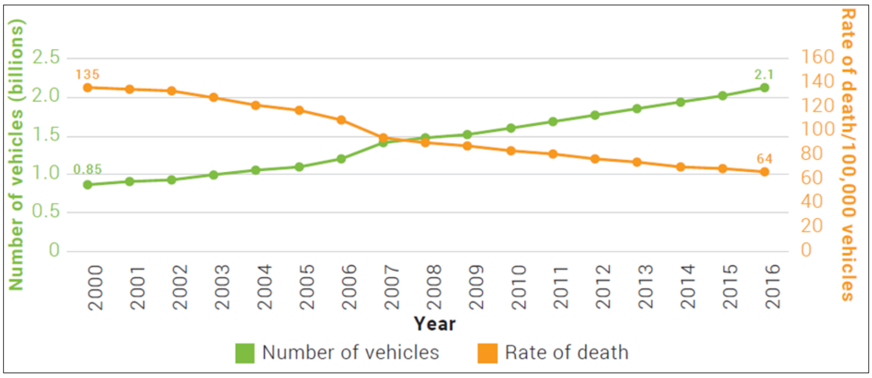


Figure 3.2: Number of motor vehicles and rate of road fatalities per 100 000 vehicles from 2000-2016 (WHO, 2018)

3.2.1 Comparison by Region

In 2016, the global fatality rate was 18.2 fatalities per 100 000 population (WHO, 2018). However, the fatality rates of countries and regions around the world differ significantly as varied levels of progress related to road safety has been made within regions. As shown in Figure 3.3, Africa has the highest road fatality rate – 26.6 fatalities per 100 000 population – which is considerably higher than the global average. South-East Asia also has a rate higher than the global average, with a rate of 20.7 fatalities per 100 000 population. The Eastern Mediterranean and the Western Pacific have rates comparable with the global average, while Europe and the Americas have the lowest road fatality rates, with 9.3 and 15.6 fatalities per 100 000 population respectively (WHO, 2018).

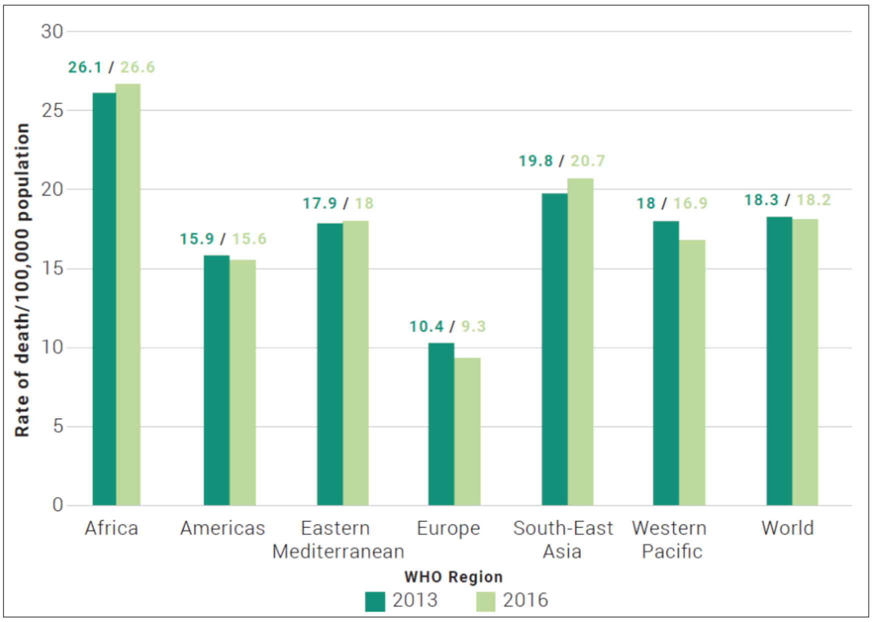


Figure 3.3: Rate of road fatalities per 100 000 population per WHO region for 2013 and 2016 (WHO, 2018)

Figure 3.3 clearly shows that there are inequalities in road safety across different regions. The risk of dying from a road traffic crash is strongly related to the income level of the region. In low-income regions, the average road fatality rate is 27.6 fatalities per 100 000 population, which is three times the average rate in a high-income region (8.3 fatalities per 100 000 population). Low- and middle-income regions clearly bear the burden of the road safety problem, as 93% of all road traffic deaths occur in these regions – regions that only have 60% of the world's vehicles. The situation is even more shocking when looking at low-income regions alone: these regions only have 1% of the world's vehicles, but 13% of all road traffic deaths (WHO, 2018). These values, along with Figure 3.3, support the claim made by Nantulya and Reich (2002) that a disproportionate amount of road traffic fatalities occur in developing regions (mostly low- and middle-income countries).

Fatality rates in developing regions are continuing to rise while the opposite is true in developed regions (mostly high-income countries). Since 2013, 87 low- and middle-income countries recorded an increase in the number of road traffic deaths compared to 17 high-income countries, and no low-income countries experienced a reduction in the number of deaths (WHO, 2018).

One explanation for the increase in fatality rates in developing regions is the increase in motorisation. As developing countries continue to grow and advance, the number of vehicles continue to increase, especially since many of these countries currently have low motorisation rates. Poor enforcement of road safety also contributes to high fatality rates in low-income countries, as there are often inadequate resources, poor administration, and corruption. A further reason for the high fatality rate in developing regions is poor public healthcare and access to health services, which leads to inadequate treatment of road traffic injuries (Nantulya & Reich 2002). Contrary to the situation in developing regions, developed regions generally have a decreasing road fatality rate, which is due to better infrastructure, enforcement, and healthcare.

3.2.2 Vulnerable Road Users

Vulnerable road users, such as children, the elderly, pedestrians, cyclists, and motorised two- and three-wheelers bear the burden of road traffic fatalities and injuries, especially in developing countries. Globally, road traffic fatalities are the leading cause of death for children and young adults (ages 5-29 years), which is a major concern (WHO, 2018). Furthermore, the number of fatalities per 100 000 population for children aged 0-14 years was found to be six times greater in low-income countries than in high-income countries (Nantulya & Reich 2002), which again speaks to poorer regions bearing the brunt of the road safety burden. The elderly population (ages 65 and above) are also at a greater risk of dying from road crashes, although this is partly due to the increased population share of this age group (ITF, 2019a).

Globally, more than 50% of all road traffic fatalities are represented by vulnerable modes of transport, namely walking, cycling, and motorcycling (two- and three-wheelers) (Figure 3.4). Africa, a developing region, has the highest proportion of pedestrian and cyclist fatalities (44%) (WHO, 2018). In developing countries, the majority of the population cannot afford private vehicles or good public transport services and are, therefore, forced to walk or cycle to their destinations, which contributes to this high percentage. The poor non-motorised transport infrastructure and increasing levels of motorisation in these regions contribute to this fact. South-East Asia, another developing region, has the highest proportion of motorised two- and three-wheeler fatalities (43%), which is partly, due to the rapidly increasing mode share of this transport mode in this region (WHO, 2018).

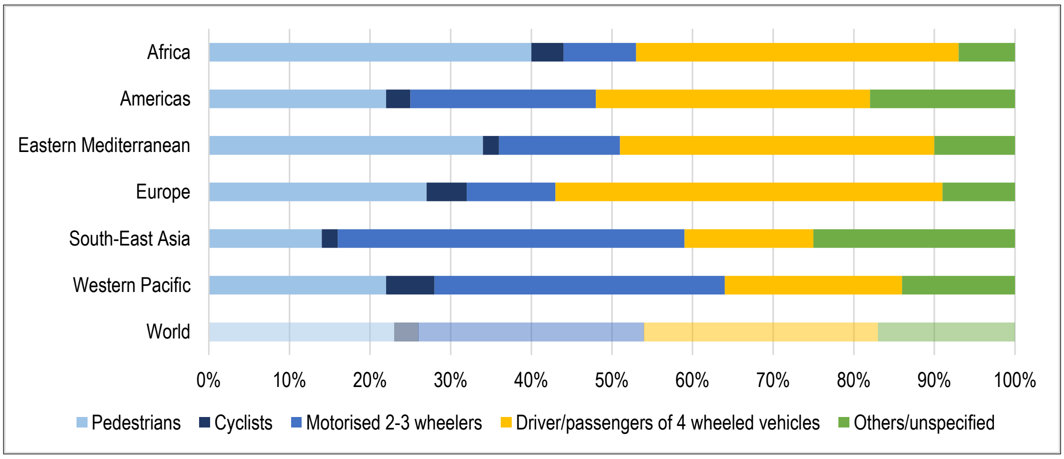


Figure 3.4: Distribution of road fatalities by road user for WHO regions (based on WHO data, 2018)

Although there has been progress in improving road safety, vehicle occupants benefit significantly more from these improvements than other modes. Since 2009, the proportion of vehicle occupants killed in road crashes globally has decreased, while the proportion of pedestrians, cyclists, and two- and three-wheelers killed in road crashes has increased by 8% (ITF, 2019a; WHO, 2009; WHO, 2018). These vulnerable road users are often part of the poor and marginalised groups in society, and "bear a disproportionate share of the disadvantages of motorisation", namely injury and death (Peden et al., 2004:10). Therefore, this is not only a health and safety issue, but also an equity issue, as "income and social status become social determinants of road traffic deaths and injury" (WHO, 2018:10).

3.2.3 Contributory Factors to Road Crashes

When analysing fatalities caused by road crashes, it is important to understand the factors that contributed to the crashes occurring in the first place. These contributory factors can be grouped under three main categories: human factors, vehicle factors, and roads and environment. Literature shows that human factors are the biggest contributors to road crashes by a large margin, with approximately 86-94% of crashes caused by human factors in the United Kingdom (UK), the United States (US), and South Africa (Table 3.1). Vehicle factors play a small role in crashes in developed countries, such as the UK and the US, but in developing countries like South Africa, vehicles contribute to a slightly higher proportion of crashes as they are often older and have more defects. The roadway and surrounding environment also contribute to crashes and are the main cause of 2-10% of road crashes in the UK, US, and South Africa.

Table 3.1: Distribution of contributory factors to crashes in three countries

	HUMAN FACTORS	VEHICLE FACTORS	ROADS & ENVIRONMENT*	OTHER
United Kingdom[1]	87%	2%	10%	1%
United States[2]	94%	2%	2%	2%
South Africa[3]	86%	5%	9%	-

[1] US DoT, 2018; [2] UK DfT, 2015; [3] RTMC, 2019 (fatal crashes only)
* The way this is measured is not standardised. Roads in the UK generally invite lower speeds than roads in the US

Human factors that contribute to road crashes include jaywalking, distracted driving, speeding, intoxication, fatigue, and reckless behaviour, such as unsafe overtaking unsafe following distances (Botha & van der Walt, 2006; US DoT, 2018; UK DfT, 2015). Jaywalking is common in urban environments, especially those with poor pedestrian infrastructure, and has been found to contribute to up to 40% of fatal crashes (Verster & Fourie, 2018; Choi et al., 2013). Distracted driving is another human factor that has a growing contribution to the number of road fatalities. For example, texting while driving has been found to increase crash risk by a factor of 23 (Farmer et al., 2010).

It is generally accepted in literature that speeding causes approximately 30% of all fatal crashes (Adminaité-Fodor and Jost, 2019; OECD, 2006; Trotta, 2016). Therefore, it is critical to manage vehicle speeds, especially as every 1% increase in average speed produces a 4%

increase in fatal crash risk (Finch et al., 1994). Currently, only 46 countries, representing 35% of the world's population, have laws setting speed limits that align with best practice (which includes urban speed limits not exceeding 50 km/h) (WHO, 2018). As speed reduction has the potential to significantly reduce the number of fatal crashes, ensuring good speed management of roads is essential.

Intoxication of both drivers and pedestrians is another common factor that results in fatal crashes, with estimations of 5-35% of all fatal crashes being alcohol related (Vissers et al., 2018). Pedestrians and drivers who are drunk or under the influence of drugs are more likely to be involved in road crashes, as their walking/driving behaviour and movement is impaired. Blood alcohol concentrations (BACs) of above 0.00 g/dl have been shown to worsen driving behaviour, but once BACs reach 0.05 g/dl, the risk of a crash increases exponentially (WHO, 2018). Additionally, reducing BACs from 0.1 to 0.05 g/dl has the potential to reduce road fatalities by up to 18% (Fell & Voas, 2006). Currently only 45 countries, representing 30% of the world's population, have laws setting speed limits that align with best practice (which includes a BAC limit not exceeding 0.05 g/dl) (WHO, 2018).

Vehicle safety and roadworthiness is also important when considering the causes of road crashes. Vehicle factors that contribute to crashes include burst tyres, faulty brakes, smooth tyres, vehicle overloading, faulty lights, and faulty steering. Tyre-related problems (bursting and smoothness) and defective brakes make up the highest proportion of vehicle factor-related crashes (35-57% and 14-50% respectively) (RTMC, 2019; UK DfT, 2015; US DoT, 2018). Vehicle defects can be controlled and limited to a certain extent through strict safety standards and regular roadworthiness tests. Vehicle safety standards, such as electronic stability control and advanced braking, need to be followed by all manufacturers to reduce the number of fatalities caused by defective vehicles. Currently, 80% of countries do not have vehicle safety standards that align with the United Nation's (UN) priority standards, which is a major cause for concern (WHO, 2018).

Substantial interventions are also possible to mitigate the impact of poor road conditions and surrounding environments that lead to road crashes. Sharp bends in the road, slippery road surfaces, poor visibility, and poor lighting are all road/environment factors that contribute significantly to crashes (RTMC, 2019; UK DfT, 2015; US DoT, 2018). Stigson et al. (2008) found that between the three factors that contribute to crashes (human, vehicle, and road/environment), road-based factors were most strongly linked to the severity of the crash. It is essential that road infrastructure and its surrounding environment is well-designed and safe, as this can reduce the severity of crash outcomes (i.e., fatalities and serious injuries) by up to 80% (PIARC, N.d.).

3.2.4 Case Study: South Korea

The overall road fatality rate in South Korea has decreased dramatically over the past two decades, from 25.6 fatalities per 100 000 in 2000 to 8.6 fatalities per 100 000 population in 2019 (WHO, 2021). Additionally, the country reduced the number of child fatalities in road crashes by 95% between 1988 and 2012, which is a remarkable achievement (Figure 3.5).

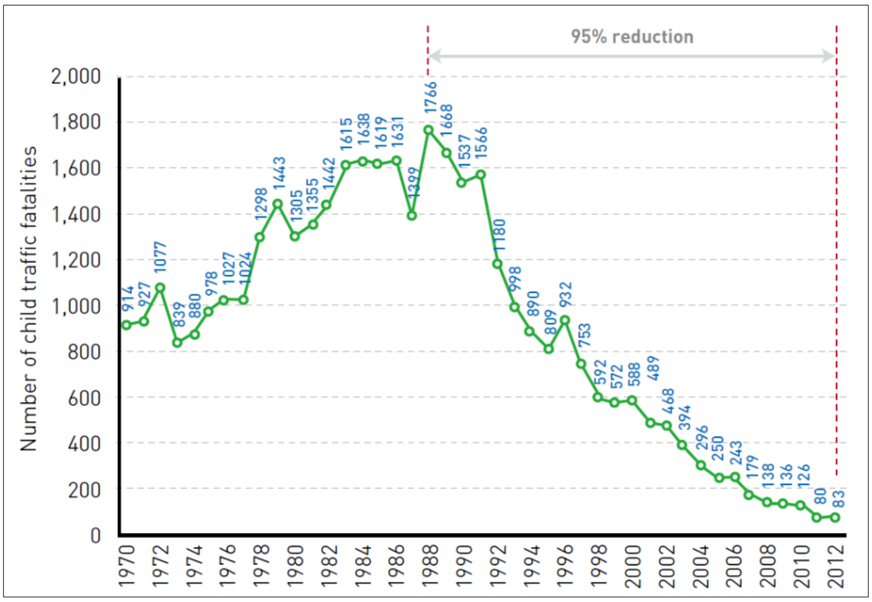


Figure 3.5: Trend of child fatalities in South Korea from 1970-2012 (Jaehoon et al., 2014)

This massive decrease in road fatalities for children under the age of 14 was achieved through various infrastructure and policy interventions. Programmes to improve school zones were implemented, which included the installation of traffic safety equipment such as safety signs and pedestrian traffic signals, the installation of sidewalks and speed bumps, and limiting the speed in the area to 30 km/h. Road safety education programmes for children were also initiated, as well as various policies that informed the protection of children and the improvement of road safety in school zones (Jaehoon et al., 2014).

This case study shows how targeted interventions and strategies over a period of time can have substantial lasting impacts in road safety improvement and should serve as a lesson to other countries needing to reduce their road fatality rates – especially for children.

3.3 African Status Quo

Africa has the deadliest roads in the world. Approximately 650 people die every day on African roads, and the region has a fatality rate of 26.6 road fatalities per 100 000 population. This is significantly higher than the global average and almost three times greater than Europe's (WHO, 2016; WHO, 2018). The severity of Africa's road safety problem compared to the rest of the world in shown in Figure 3.6, where darker shading indicates a higher fatality rate.

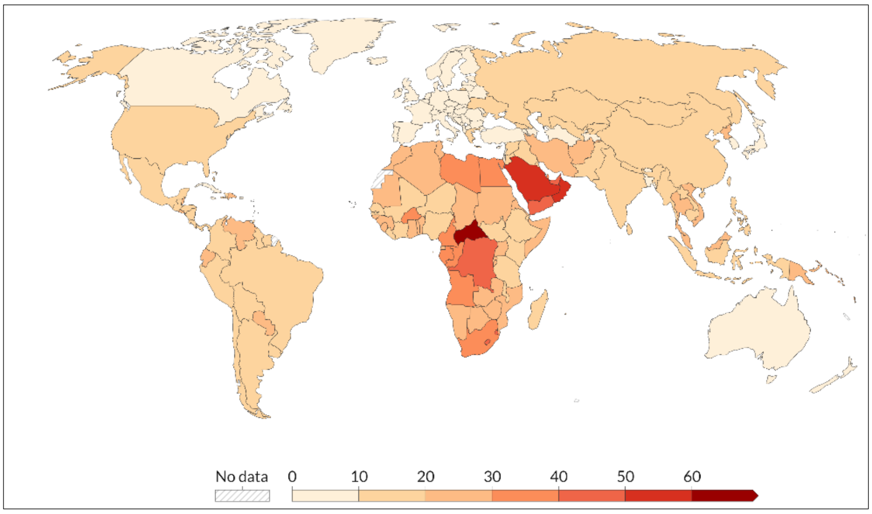


Figure 3.6: Map of road fatalities per 100 000 population per country for 2019 (Our World in Data, 2022)

While Europe and the America's road fatality rate per 100 000 population has continued to decrease (see Figure 3.3 in Section 3.2), Africa's fatality rate is increasing and is expected to double between 2015 and 2030 (WHO, 2015). Additionally, Africa is the least motorised region in the world with only 2% of the world's registered vehicles, yet it has 20% of the world's road fatalities and the highest rate of road fatalities per 100 000 population (Peden et al., 2013). A further issue is that road fatalities are highest among the economically active population (aged 15-59 years), who are often the breadwinners of the household (AfDB, 2013). These fatalities leave the remaining members of the household financially unattended (Verster & Fourie, 2018).

These facts show that Africa disproportionally bears the burden of road fatalities and emphasises that road safety is a massive problem on the continent. With population and motorisation levels continuing to increase in this region, there is much work to be done to improve road safety and limit the number of fatalities caused by road traffic crashes.

3.3.1 Comparison by Country

Road fatality rates significantly by country within the continent (Figure 3.7). A few countries have fatality rates below the global average, namely Egypt, Mauritius, and the Seychelles, while 42 countries have fatality rates above the global average. Eleven countries have rates higher than 30 fatalities per 100 000 population, with Liberia having the highest rate of 35.9 fatalities per 100 000 population (the highest in the world) (WHO, 2018).

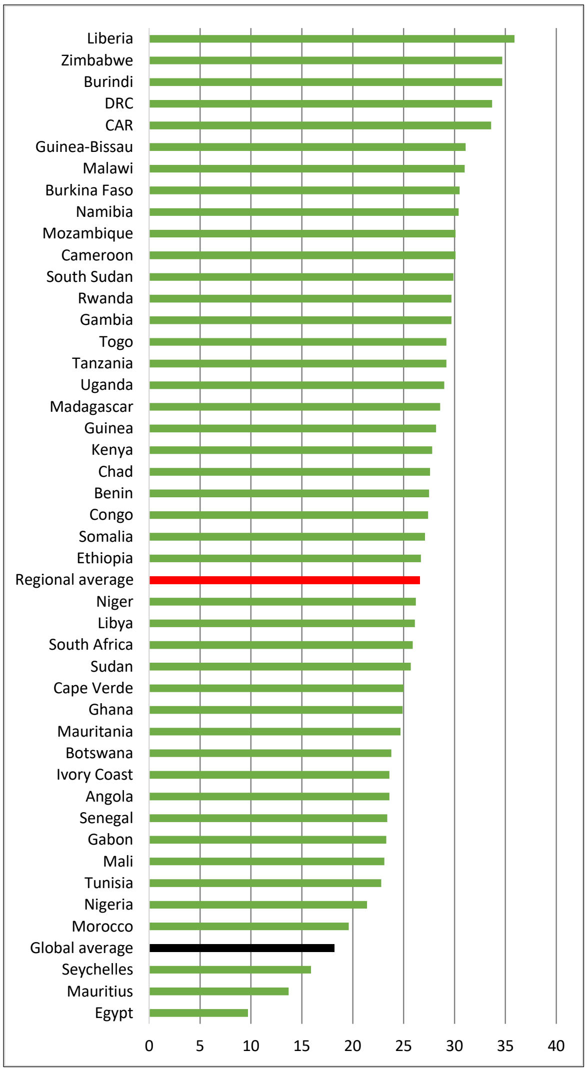


Figure 3.7: Road fatality rate per 100 000 population in 46 African countries (author's figure based on WHO 2018 data)

In terms of legislation and policy, the majority of African countries have national laws that address key risk factors, but very few of them have laws that meet best practice legislative criteria (Table 3.2). Seatbelt laws have the most countries (40%) that meet the best practice legislative criteria, which in this instance is defined as having a “national seatbelt law applied to drivers, front seat and rear seat passengers” (WHO, 2016:9). While 95% of African countries have a form of drink-driving law, only eight (including South Africa) have a blood-alcohol content (BAC) limit of ≤ 0.05 g/dl. Only one country, Algeria, has legislation for drink-driving that adheres to best practice, which is defined as having a “national drink-driving law based on BAC where the BAC limit for general population is ≤ 0.05 g/dl and the BAC limit for young/ novice drivers is ≤ 0.02 g/dl” (WHO, 2016:8).

Table 3.2: Best practice legislative criteria met by countries in the African region (WHO, 2016:9)

RISK FACTOR	COUNTRIES MEETING LEGISLATIVE CRITERIA FOR BEST PRACTICE
Speed	Algeria, Burkina Faso, Kenya, Madagascar, Rwanda, Sao Tome and Principe (16%)
Drink-driving	Algeria (2%)
Motorcycle helmets	Botswana, Cabo Verde, Ghana, Madagascar, Malawi, Swaziland (14%)
Seatbelts	Algeria, Angola, Botswana, Burkina Faso, Eritrea, Ethiopia, Ghana, Kenya, Mauritius, Mozambique, Namibia, Seychelles, Sierra Leone, South Africa, Togo, Uganda, Zambia (40%)
Child restraints	Angola, Botswana, Burkina Faso, Cabo Verde, Ethiopia, Eritrea, Guinea, Mozambique, Zambia (21%)

It is encouraging to note that 74% of African countries have road safety agencies whose aim is to coordinate the implementation of a national road safety strategy. However, these agencies need authority, resources, and capacity to do so – things that are often scarce in African countries. Additionally, there is very poor crash data recording and management in the region, which adds to the difficulties of road safety agencies who are trying to improve the status quo of their areas (WHO, 2016; AfDB, 2013).

3.3.2 Modes and Infrastructure

Consistent with trends associated with developing regions, vulnerable road users in Africa bear the brunt of the road safety burden. More than half of all road traffic fatalities in Africa are pedestrians, cyclists, and motorised two- and three-wheelers (Figure 3.8), with pedestrians accounting for 40% of the total fatalities (WHO, 2018). It is discouraging to see that only one African country (South Africa) has signed up to the UN safety standard that protects pedestrians in a road crash, and that only 23% of African countries have policies that support the separation of vulnerable road users from the rest of the traffic (WHO, 2015).

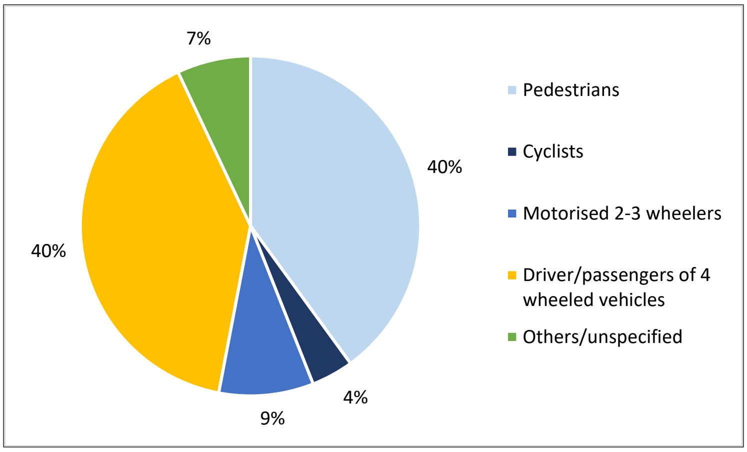


Figure 3.8: Distribution of fatalities by road user type in Africa (WHO, 2018)

The choice of transport mode in Africa is, significantly, influenced by socio-economic factors, such as income and education. In Kenya, for example, 9% of travellers who had no formal education used private cars compared to 81% of those with secondary education or higher (Nantulya & Reich, 2002). People with little or no education often cannot afford safer or more convenient transport modes and are forced to use more affordable but more dangerous modes, such as walking, cycling, minibuses, or two- or three-wheelers. As said by a commuter in Lagos, Nigeria (Nantulya & Reich, 2002:1140):

> *"Many of us know most of the buses [danfos, 'flying coffins'] are death traps, but since we can't afford the expensive taxi fares, we have no choice but to use the buses."*

In addition to increasing motorisation, poor healthcare and access to health services, and poor enforcement, inadequate infrastructure also contributes to the poor road safety situation in Africa. For example, there is a strong inverse relationship between the percentage of paved roads and fatality rates: the fewer paved roads there are, the higher the fatality rate. Many countries in Africa do not have a high percentage of paved roads, with only one country, South Africa, having a paved road network greater than 100 000 km (CIA, 2022). Other infrastructure-related issues include poor road surfacing, poor visibility, narrow roads, and a significant lack of pedestrian footpaths, to name a few (Theofilatos et al., 2020). Overall, the road safety situation in Africa is dire, and drastic measures need to be taken to improve road safety across the continent and save thousands of lives.

3.3.3 Case Study: Nairobi, Kenya

Kenya has a road fatality rate of 27.8 fatalities per 100 000 population, which is significantly above the global average, indicating that road safety is a problem in this country. Nairobi, the capital of Kenya, has a rapidly growing population of over 4 million that is placing increasing pressure on the city's transport system and increasing the chances of road traffic crashes (Chepchieng et al., 2015).

The Nairobi-Thika Highway is a major corridor that links downtown Nairobi to the suburbs, and between 2006 and 2009, 246 fatal crashes occurred on the highway (Chepchieng et al., 2015). An upgrade of the highway occurred from 2010-2012, which aimed to "considerably decrease the crash rate by minimising vehicle conflicts with traffic interchanges and by providing separate service roads for local and non-motorised traffic" (Chepchieng et al., 2015:200). This upgrade was successful, as fatalities were reduced from 76 at the peak in 2009 to 31 in 2013 – a decrease of 59% (Figure 3.9). The significant reduction in fatalities between 2010 and 2012 is due to the vehicle speed reduction during construction. Overall, the number of accidents decreased from before the highway upgrade to after the highway upgrade.

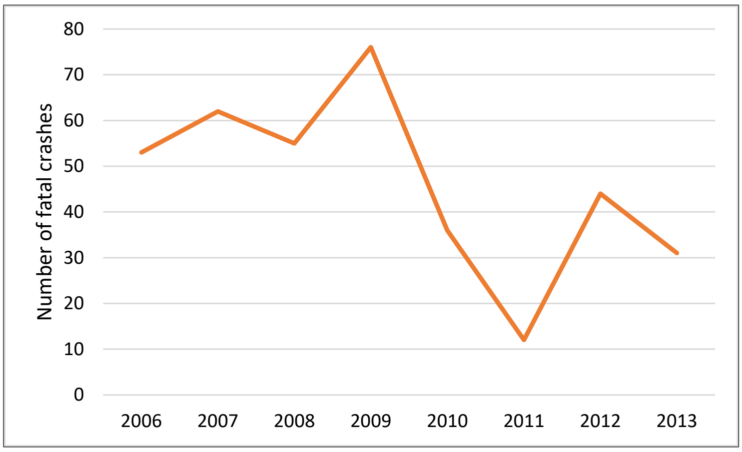


Figure 3.9: Number of fatal crashes on the Nairobi-Thika Highway from 2006-2013 (Chepchieng et al., 2015).

This case study shows that road upgrade/rehabilitation projects (i.e., road infrastructure improvements) have the potential to improve the road safety of a corridor. The number of speed-related crashes increased due to an overall improvement in road quality, but the number of crashes caused by poor road geometry, lack of pedestrian facilities, and at-grade junctions reduced significantly (Chepchieng et al., 2015).

3.4 South African Status Quo

South Africa has a road traffic fatality rate per 100 000 population of 21.3[1] (RTMC, 2019; STATSSA, 2019), and is ranked 39 out of 175 countries for the highest road fatality rate, placing it in the worst 25% of countries around the world (WHO, 2018). Although the country has significantly reduced its fatality rate from 2007 (Figure 3.10), which is encouraging progress, a fatality rate of 21.3 fatalities per 100 000 population is still unacceptable (by way of comparison, the average in the European Union was 5.1 fatalities per 100 000 population in 2019 (ITF, 2019b)).

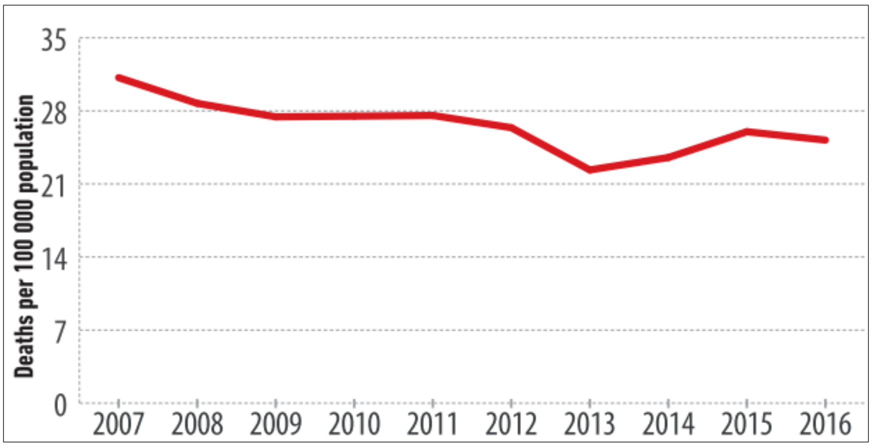


Figure 3.10: South African road fatalities per 100 000 population from 2007-2016 (WHO, 2018)

Over 12 500 people in South Africa die each year from road traffic injuries (RTMC, 2019), which costs the economy approximately R162 billion (3.5% of GDP) per year (Vanderschuren & Roux, 2019; ITF, 2019b). The RTMC is the lead agency for road safety and monitors the National Road Safety Strategy, which aims to reduce fatalities and injuries by 50% from the

[1] The RTMC and the WHO define road fatalities differently. The RTMC reports on exact fatality data received from the South African Police Service. The WHO reports on a corrected value, which is the RTMC value corrected for missing data i.e., those road fatalities that do not occur immediately but within 30 days of the crash.

2010 baseline by 2030 (in line with the UN's Second Decade of Action). The target to achieve this goal is 6 984 fatalities in 2030, which is 56% of the total fatalities in 2019 (ITF, 2019b). The risk of road fatality measured as fatalities per 10 000 registered vehicles was 10.4 in 2018, which is a 26% decrease from 2000. While this decrease is an encouraging sign, the fatality rate per 10 000 registered vehicles in South Africa is 20 times higher than in the best performing countries, indicating that a lot still needs to be done (ITF, 2019b).

3.4.1 Fatalities Per Road User, Gender, Race, and Age

Consistent with trends in Africa and developing regions around the world, vulnerable road users bear the brunt of the road safety burden in South Africa. Vulnerable, non-motorised modes, namely walking and cycling, make up over 40% of fatalities (RTMC, 2019). In 2019, 40.5% of all road traffic fatalities were pedestrians, which is a 2.5% increase from 2018 (RTMC, 2019). Cyclists only make up a small proportion of the modal share and contribute to 1% of the total fatalities (Figure 3.11).

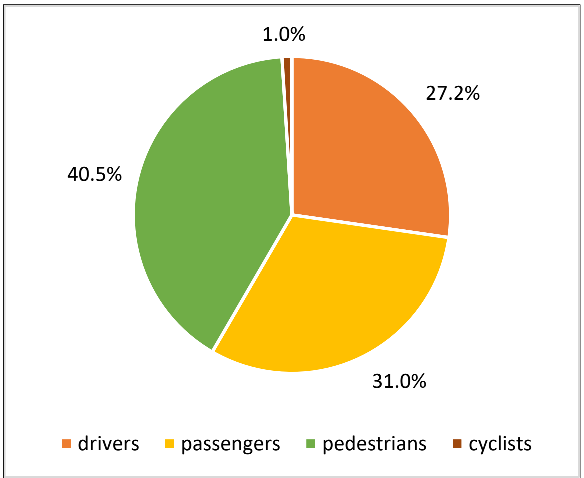


Figure 3.11: Distribution of fatalities by road user (based on RTMC 2019 data)

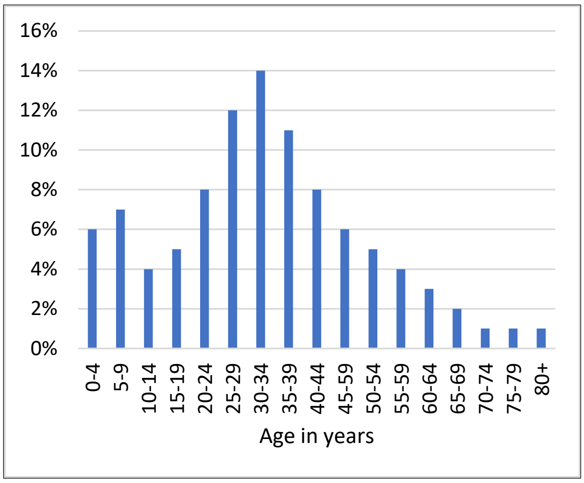


Figure 3.12: Distribution of pedestrian fatalities by age (based on RTMC 2019 data)

Children and teenagers (ages 0-19 years), who are particularly vulnerable road users, make up 22% of all pedestrian fatalities (Figure 3.12), 21% of passenger fatalities, and 14% of cyclist fatalities (RTMC, 2019). In 2019, nearly 10 000 children walked all the way to school, so pedestrian safety for this population group is of the utmost importance (STATSSA, 2020). Figure 3.12 also shows that the economically active population (ages 15-59 years) make up 82% of pedestrian fatalities. This is especially worrying as when household breadwinners pass away, the rest of the household is left to fend for themselves financially, something that they are often unable to do (Verster & Fourie, 2018).

Looking at fatality distribution by gender, it can be seen that males are disproportionally affected by road crashes. The national gender distribution is 49% male and 51% female (STATSSA, 2019), while the road fatality distribution is 76% male and 22% female (Figure 3.13). This could be explained by the fact that males are more likely to exhibit risky behaviour on the roads. However, it also reflects the deeper issues of limited mobility, access, and opportunity for women, especially in developing countries (Yan & Job, 2021).

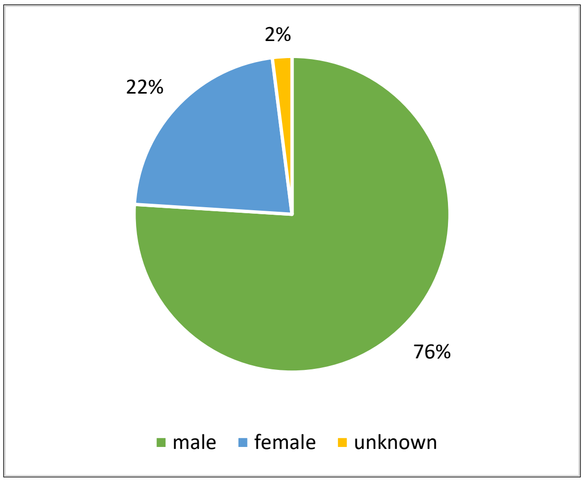


Figure 3.13: Distribution of fatalities by gender (based on RTMC 2019 data)

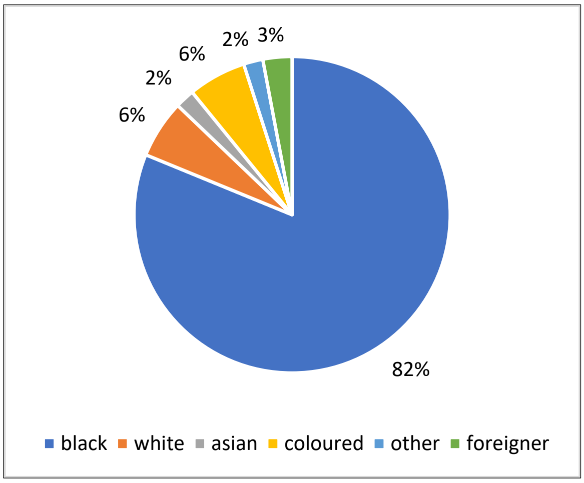


Figure 3.14: Distribution of fatalities by race (based on RTMC 2019 data)

The vast majority of fatalities that occurred were black individuals (Figure 3.14). This is to be expected, as 80.7% of people in South Africa are black (RTMC, 2019). The fatality distribution also aligns with population distribution for the other population groups (STATSSA, 2019).

3.4.2 Comparison by Province

Road fatalities vary within the nine provinces in South Africa, as shown in Figure 3.15. Gauteng and KwaZulu-Natal have the highest number of fatalities in absolute terms (2 453 and 2 331 respectively), which is to be expected as they are the provinces with the highest populations. The Northern Cape has the lowest number of absolute fatalities by far (384), which also aligns with the fact that it has the lowest population among the provinces (STATSSA, 2019). While six provinces have reduced their fatality numbers from 2018, Mpumalanga, the

Northern Cape, and the Western Cape have all increased, with the Western Cape increasing by the largest percentage (11% increase) (RTMC, 2019).

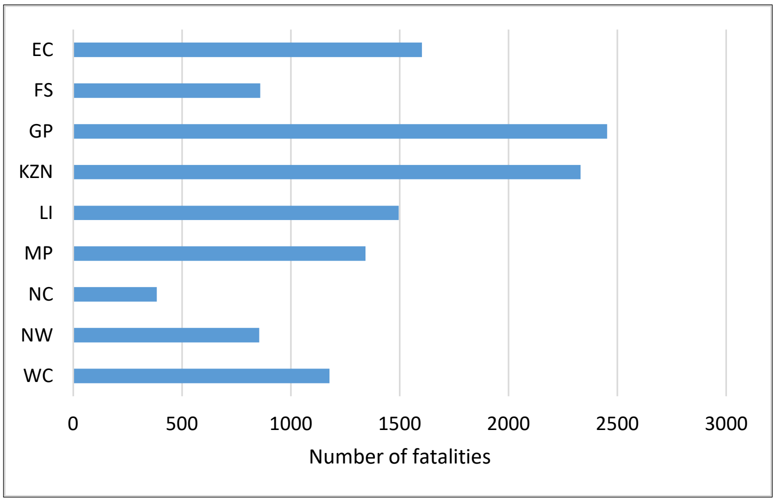


Figure 3.15: Fatality numbers per province (based on RTMC 2019 data)

In terms of road fatality rate per 100 000 population, i.e., the relative risk of dying due to road crashes (WHO, 2018; Vanderschuren & Roux, 2018), Gauteng and the Western Cape are the safest provinces, with 16.2 and 17.2 fatalities per 100 000 population, respectively (Figure 3.16). The Northern Cape, the Free State, and Mpumalanga are the least safe provinces, with 30.4, 29.8, and 29.2 fatalities per 100 000 population respectively.

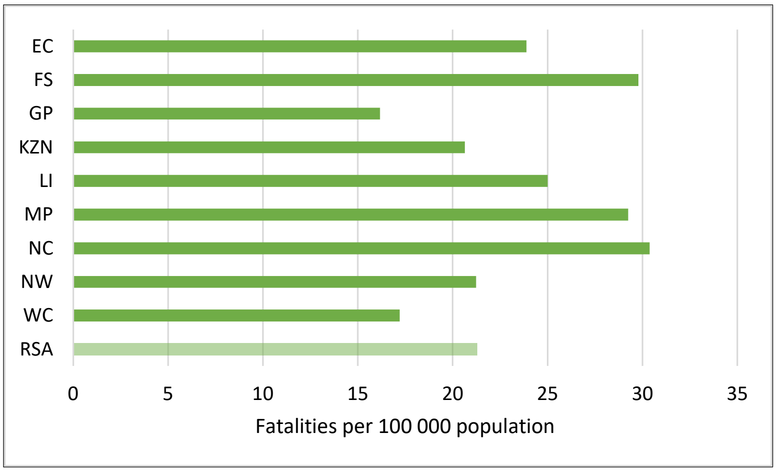


Figure 3.16: Fatalities per 100 000 population per province (based on RTMC 2019 and STATSSA 2019 data)

3.4.3 Contributory Factors to Fatal Road Crashes

Human factors account for 86% of all fatal crashes in South Africa. Of this 86%, jaywalking (32%), hit and runs (19%), and speeding (10%) are the three most prominent human factors that contribute to fatal crashes Other important factors to note are intoxicated drivers and/or pedestrians, and driver fatigue (RTMC, 2019; Botha & van der Walt, 2005).

Jaywalking accounts for 28% of all contributory factors in South Africa, making it the single most important factor causing fatal crashes (RTMC, 2019). The prevalence of jaywalking (pedestrians crossing the road without the use of crossing facilities) is, partly, due to the lack of congruence of pedestrian desire lines and pedestrian crossing facilities. For example, many informal settlements are located next to high mobility routes where pedestrians have to cross highways to access services on the other side. While crossing facilities are often located along the highway, pedestrians choose not to use them as the route they would have to travel diverges too much from their desire line. In order to reduce the occurrence of jaywalking (and the many fatalities associated with it), it is important to investigate and understand pedestrian desire lines and introduce crossings that align with these desire lines (Behrens, 2002; Behrens & Makajuma, 2017; Ojungu-Omara & Vanderschuren, 2006).

Speeding is also a significant problem in South Africa. The WHO (2018) recommends an urban speed limit of 50 km/h – for pedestrians involved in vehicle crashes, the risk of fatality rises rapidly (4.5 times from 50 km/h to 65 km/h). However, South Africa has an urban speed limit of 60 km/h, which correlates to a fatality risk of 90% (Pasanen, 1991). A reduction in urban speed limits is important, as some research shows that a reduction by 6 km/h could lead to nine less fatal crashes per month (Ojungu-Omara & Vanderschuren, 2006). Additionally, increased policing is needed to enforce speed limits and fine perpetrators who speed.

Vehicle factors only contributed to 5% of fatal crashes in 2019, with most vehicle-related crashes occurring as a result of a burst tyre (50%). Other important vehicle factors include faulty brakes and smooth tyres, which contributed to 14% and 7% of vehicle-related crashes respectively (RTMC, 2019). As burst tyres are by far the most common vehicle factor for fatal crashes, steps should be taken towards greater education and enforcement. The public should be educated about the risk of tyres bursting and what they can do to prevent it, and law enforcement should crack down on overloaded vehicles, which have a high risk of burst tyres (Ojungu-Omara & Vanderschuren, 2006).

Road and environmental factors contributed to 9% of fatal crashes in 2019. Roads with sharp bends (17%), poor visibility (14%), and slippery road surfaces (11%) were the three main contributory factors to these road/environment-related crashes, but poor lighting, poor road surfaces, stray animals, and blind corners are also important factors to note (RTMC, 2019). Engineering solutions to mitigate these road factors include improved street lighting, increased road signage and speed reduction at sharp bends, and seals applied to road surfaces to increase skid resistance (Ojungu-Omara & Vanderschuren, 2006).

3.4.4 Case Study: Western Cape, South Africa

The Western Cape province, home to the City of Cape Town, has made the most progress among the nine provinces in reducing its road fatality rate. In 2005, the province had a road fatality rate of 30.0 fatalities per 100 000, and in 2019, this had reduced to 17.2 fatalities per 100 000 population – a decrease of 43% (RTMC, 2019; STATSSA, 2019; Vanderschuren et al., 2020). This is very encouraging progress. However, as mentioned in Section 3.4.2, the Western Cape had the largest increase in absolute fatalities in 2019 (RTMC, 2019). While the Western Cape is the second safest province in the country after Gauteng, according to fatality rates per 100 000 population, the fact that absolute fatalities are rising is a cause for concern.

Looking in more detail at areas within the province, there are many areas that have fatality rates above both the global and African averages (Figure 3.17). The towns of Leeu Gamka and Laingsburg are especially worrying cases, with staggeringly high fatality rates per 100 000 population of nearly 500 and over 350 persons, respectively. Both of these are small towns located along the N1, where the majority of fatalities are people travelling through as opposed to residents. Additionally, long-distance minibus taxis contribute to many passenger fatalities in these towns (Vanderschuren et al., 2017a). Woodstock, De Doorns, Touwsrivier, Maitland, Durbanville, Bellville, Nyanga, and Beaufort West all have fatality rates per 100 000 population over 50 persons, which is also a huge cause for concern.

While Khayelitsha and Philippi, two low-income areas in Cape Town, have fatality rates comparable with Africa and the rest of the world, they have very high absolute fatality numbers (approximately 68 and 38 fatalities, respectively, occur each year). These are unacceptable values for such small areas.

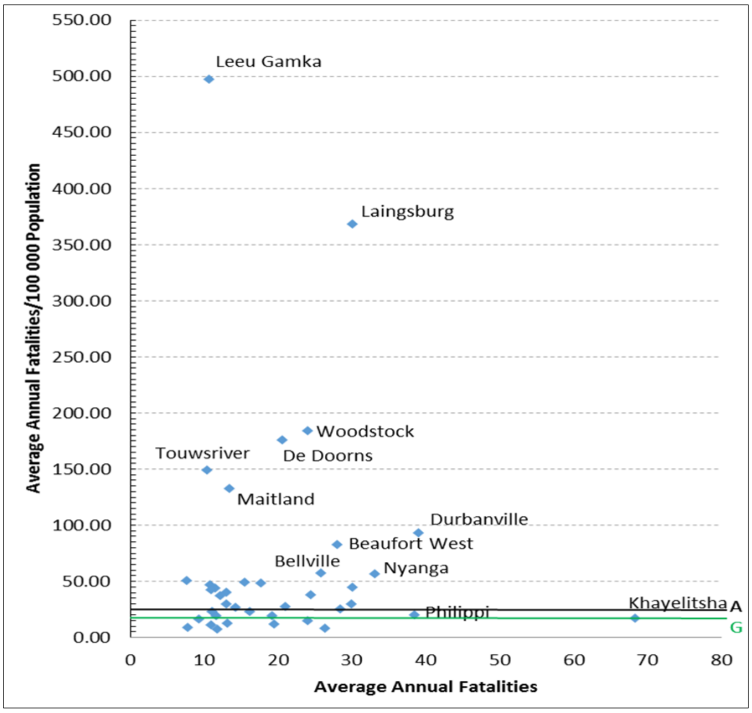


Figure 3.17: Average annual fatalities versus average annual fatalities per 100 000 population in the Western Cape (Vanderschuren et al., 2017a, based on FPL 2011-2015 data)

In order to continue the improvement of road safety in the province, research done by Vanderschuren et al. in 2020 investigated the effectiveness of potential road safety measures in the Western Cape. This research found that speed reduction through rumble strips, improved lighting, and improved motorcycle emergency services are the best and most cost-effective road safety measures for the province. In the case of improving emergency services, the benefits outweigh the costs in the shortest amount of time. This is followed by enforcement (e.g., speed-over-distance) and educational campaigns. Infrastructure measures take the longest to break-even, with the exception of the installation of rumble strips (Vanderschuren et al., 2020). It is crucial that these identified measures be implemented in the Western Cape to continue to save lives on the province’s roads.

3.5 Résumé

This chapter set out to understand the road safety status quo at a global, regional, and local scale. Globally, it was found that approximately 1.35 million road traffic fatalities occur on the world's roads each year, and that the absolute number of road fatalities continues to increase. However, the global fatality rate per 100 000 population has stabilised at 18 persons, which is a positive sign (WHO, 2018). Fatality rates in developing regions such as Africa and South-East Asia continue to increase, unlike rates in developed regions such as Europe and the Americas. Vulnerable road users were found to bear the brunt of the road safety burden around the world. Vulnerable modes, such as walking and cycling, and vulnerable population groups such as children and the elderly, contribute to a large proportion of fatalities (WHO, 2018).

Africa was found to have a fatality rate per 100 000 population of 26.6 persons, which is significantly higher than the global average (WHO, 2018). Africa has only 2% of the world's registered vehicles yet contributes to 20% of the world's road fatalities (Peden et al., 2013). Fatalities in this region are highest among the economically active population and highest among pedestrians, who account for 40% of fatalities across the region (WHO, 2018). It is concerning to note that very few African countries comply with the various best practice road safety standards, which urgently needs to change in order for road safety to improve (WHO, 2018).

Finally, South Africa was found to have a fatality rate of 21.3 fatalities per 100 000 population, which is a significant reduction over the last two decades (RTMC, 2019; STATSSA, 2019). Despite this positive progress, road safety is still a serious problem in South Africa, with road fatalities costing approximately 3.5% of the country's GDP (ITF, 2019b). In line with the trend in Africa as a whole, pedestrians are the road user type most impacted by poor road safety, as 40.5% of all fatalities are pedestrians. One contributing factor to this is the prevalence of jaywalking, which accounts for 28% of all fatal crashes. Additionally, the economically active population make up a large portion of these pedestrian fatalities (RTMC, 2019).

Overall, it can be seen that some encouraging progress is being made in reducing road fatalities in South Africa and around the world. However, there are still far too many people dying every day globally (an average of 3 700 fatalities per day) and in South Africa (an average of 34 fatalities per day) (WHO, 2018; RTMC, 2019). Urgent intervention is needed in areas where nothing is being done, and increased intervention needs to continue in areas where progress is being made. In order to understand and identify these areas where intervention is needed, effective road safety assessments need to be carried out. While current assessment methods provide valuable and insightful information that can be used to improve road safety, the development of a new methodology that approaches the problem from a fresh, different perspective is warranted.

4. Methodology

4.1 Introduction

This chapter will give a detailed description of the methodology followed in this research. Firstly, the research approach taken in this study will be discussed with the help of a flow chart. This will be followed by a thorough review of the 'desert' concept, which is at the core of this research. An explanation of the data and software requirements will be given, followed by a description of the selected case city for this study. The main focus of this chapter, the development of the 'road safety desert' methodology, will then be covered in detail. Finally, a résumé of the chapter will be provided.

4.2 Research Approach

The research approach followed in this study is shown in Figure 4.1. This framework acts as a useful guide to understanding the methodology and the research project as a whole. It outlines the key stages in the research process and how the different stages relate to one another. Each stage contributes to fulfilling the research objectives listed in Chapter 1.

The majority of the first part of the framework, the literature review, has been covered in detail in Chapters 2 and 3. The literature review is a crucial stage in understanding the research topic. A review of road safety assessment methodologies was given in Chapter 2, and an investigation into the road safety status quo on a global, regional, and local level was given in Chapter 3. The rest of the literature review consists of a description of the 'desert' concept and will be presented in Section 4.3 of this chapter. Understanding the 'desert' concept is essential to this research, as it forms the basis for the development of the 'road safety desert' methodology.

The review of the 'desert' concept informed the data (and software) requirements for this research. These data requirements, in turn, informed the selection of the case city (Cape Town) to which the 'road safety desert' methodology was applied. Once data was obtained and the case city selected, the process of developing the 'road safety desert' methodology began. When the methodology was completed, it was applied to Cape Town to determine the location of motorised and non-motorised transport 'road safety deserts'. This was done in order to provide proof of concept for the methodology. Finally, these results were analysed, and final conclusions and recommendations were made.

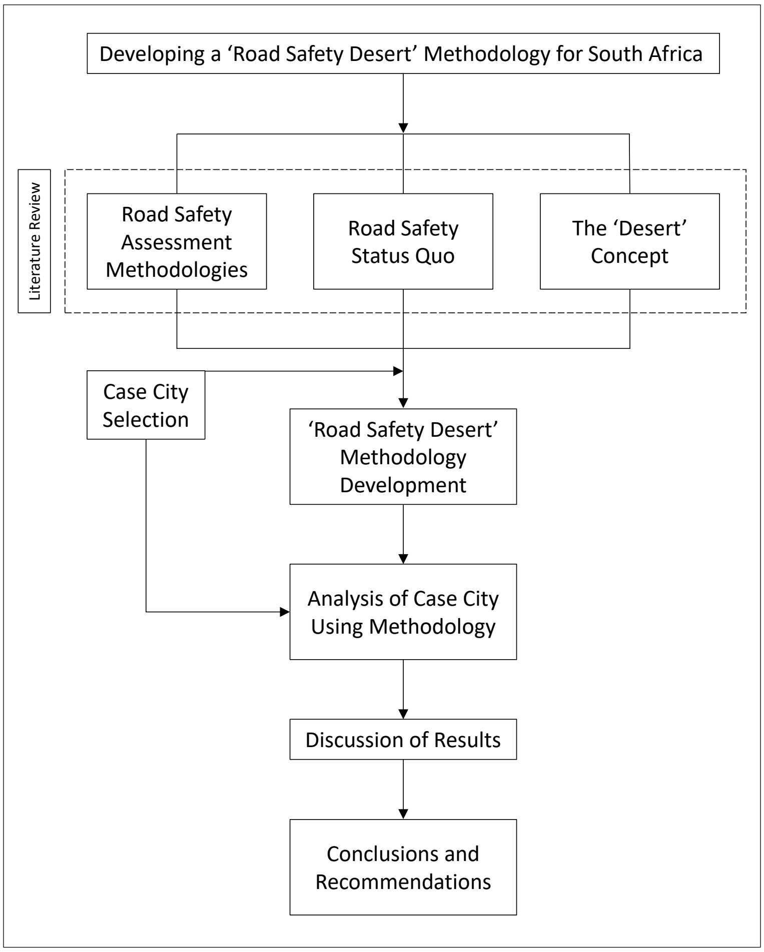


Figure 4.1: Flow chart showing research framework

4.3 The 'Desert' Concept

4.3.1 Introduction

In the preamble to the South African Constitution, former President Nelson Mandela states that the people of the country, together with their elected representatives, need to "heal the divisions of the past and establish a society based on democratic values, *social justice,* and fundamental human rights" (Constitution of South Africa, 1996:1). Simply put, social justice means equal rights and equitable opportunities for all (San Diego Foundation, 2016).

A core principle of social justice is ensuring that all people have access to goods and services regardless of their age, gender, race, income etc. (CheckUP, 2013). This type of access, however, is not available in many places around the world, and is difficult to measure.

Indicators, such as the Gini coefficient, which measures income distribution and economic inequality, are useful in giving a general picture of the standard of living in a society, but do not indicate whether said society is socially just in its access to goods and services.

Over the past three decades, the equitable distribution of goods and services has been assessed using the 'desert' concept. In academic literature, a 'desert' is based on a comparison of supply and demand, which was first used to assess access to nutritious food (Clarke, Eyre & Guy, 2002; Whelan et al., 2002; Wrigley et al., 2002; ERS, 2009). This section will explore the 'desert' concept by reviewing literature on the original version, 'food deserts'. It will then detail how the concept has been adapted to the field of transportation in the form of 'transit deserts'. Finally, a summary will be given, and conclusions made on the way forward in using this concept in the field of road safety.

4.3.2 'Food Deserts'

During the late 20th century, national surveys in the United Kingdom (UK) on food, diet, and nutrition consistently found that food consumption varied significantly by socio-economic status, age, gender, and place of residence. Additionally, these surveys found that there were considerable differences in the consumption of healthy versus unhealthy foods. For example, the 1999 National Food Survey found that in high-income households, daily fruit consumption was twice as high as that in low-income households (Wrigley, 2002).

In 1998, the UK's Social Exclusion Unit's *Bringing Britain Together* report drew attention to the lack of easy access to food shops and higher food prices faced by poorer households (Wrigley, 2002). The *Independent Inquiry into Inequalities in Health* (Acheson, 1998) linked the worsening access to food for low-income groups to the increasing health inequalities experienced by these groups, and recommended the development of "policies which will increase the availability and accessibility of foodstuffs to supply an adequate and affordable diet… to those who are disadvantaged" (Acheson, 1998:65).

The 'food desert' concept, which originated in 1995 in work done by the Low Income Project Team of the Nutrition Task Force (Beaumont et al., 1995), was used in both the *Bringing Britain Together* and Acheson report to highlight the connection between increasing health inequalities, compromised diets, undernutrition, social exclusion, and differential access to food retail provision. 'Food deserts' are defined as "those areas of cities where cheap, nutritious food is virtually unobtainable" (*The Independent*, 1997; cited in Whitehead, 1998:189).

'Food deserts' are characterised by areas where residents that do not have access to private cars or who are unable to access and/or afford public transport, are forced to shop at stores where prices are high and fresh produce is scarce, as opposed to more affordable supermarkets with healthier produce that are usually further away (Acheson, 1998; ERS, 2009). In urban areas, economic forces have forced many supermarkets to the outskirts, meaning that a grocery trip could take a shopper several bus, taxi, or train trips to get there and back. In rural areas, there is often a lack of large supermarkets, as well as a lack of public transport that can be used to travel to shops (Food Empowerment Project, N.d.).

In order to identify 'food deserts', i.e., areas that lack access to a variety of cheap, healthy food, several quantitative analyses of food access have been done. These analyses mainly use GIS mapping to identify areas that are more than a specified critical distance from a food shop (i.e., 'food deserts') (Donkin et al., 1999, 2000; Clarke, Eyre & Guy, 2002). The ultimate aim of identifying 'food deserts' using these analysis methods is to use the results to "achieve equitable access to high-quality, affordable food for everyone" (Jiao & Dillivan, 2013:23).

4.3.2.1 'Food Desert' Analysis: Case Study

An example of a 'food desert' analysis is a study done by Clarke et al. in 2002, which aimed to identify 'food deserts' and analyse food access in two urban areas in the UK, namely Leeds/Bradford and Cardiff. This study used an origin-constrained spatial interaction model to quantify the interaction between residence zones (origins) and grocery shops (destinations) using supply and demand. The demand variable is the level of consumer expenditure of a household type in a particular residence zone, and the supply variable is the attractiveness of grocery shop destinations (Clarke et al., 2002).

This model enabled the prediction of flows from residential zones to grocery shops but was not enough to identify 'food deserts'. Therefore, several performance indicators were used to help identify spatial variations in food access. The simplest performance indicator used was retail grocery square feet per household, which gave a crude indication of access to food per household. Accessibility indicators, such as a GIS-based local mapping approach, were also used in this study. While these three indicators provided an indication of the level of food access, they were also not sufficient to identify ‘food deserts’, as they were not based on the interactions between residence zones and grocery shops (Clarke et al., 2002).

The final indicators used in this study were model-based indicators, which were based on the results of the spatial interaction model. These indicators, namely aggregate level of provision and level of provision per household, were “more relevant because they are based on movements of consumers rather than simply on the geographical distribution of grocery shopping options” (Clarke et al., 2002:2047). The aggregate level of provision considers the amount of a grocery shop’s floorspace that is available to the residents of a nearby zone, i.e., their share of floorspace. The level of provision per household is the aggregate level of provision divided by the number of households in the residential zone and is relative to the rest of the city (Clarke et al., 2002).

In order to identify which areas in this case study are ‘food deserts’, it is important to consider both level of provision and accessibility. If the level of provision in an area is low but the majority of residents have access to a car (often high-income areas), the area cannot be classified as a ‘food desert’. However, if the level of provision of an area is low and the majority of residents do not have access to a car (often low-income areas), the area might be classified as a ‘food desert’. The level of provision per household for the Leeds/Bradford area was mapped, and the results showed that there was a much higher level of provision in the city centre than on the outskirts.

The example detailed above is one of several studies in which the ‘food desert’ concept has been used to identify areas with poor access to a variety of healthy, affordable food options. The results of these studies have been found to be sensible and the concept proven, which has led to the adaptation of the concept for use in other fields, namely transportation.

4.3.3 ‘Transit Deserts’

The term ‘transit desert’ was derived from the ‘food desert’ concept and was first used by Jiao and Dillivan (2013) when researching public transport services in four major US cities. As defined by Jiao and Dillivan (2013:24), transit deserts are “areas that lack adequate public transit service given areas containing populations that are deemed transit dependent”. Transit-dependent populations are those persons who are too young, too old, or too poor to drive private vehicles, people with disabilities, and other individuals who are unable to drive (Grengs, 2001).

The development of the ‘food desert’ analysis led to the development of a similar analysis for determining the location of ‘transit deserts’. The aim of the ‘food desert’ analysis can be reworded to describe the aim of the ‘transit desert’ analysis: to identify ‘transit deserts’ and ultimately “to achieve equitable access to high-quality, affordable public transport for everyone” (Newlands, 2020).

‘Transit deserts’ are areas where transit demand exceeds transit supply, and are usually found in outer-urban, peripheral areas of a city, as well as downtown areas. This is mainly because transit services require a high demand concentration, which can be found in city centres, with transit supply decreasing as the distance from the centre increases, as absolute demand decreases. Additionally, there is often a lack of infrastructure on the periphery of a city due to rapid development, which is another factor leading to the presence of ‘transit deserts’ in these areas (Jiao & Dillivan, 2013; Newlands, 2020).

Categories that are used to derive common characteristics of ‘transit deserts’, as proposed by Allen (2014:6), are neighbourhood form and physiography, time spent and ease of accessing public transport, and user demographics. When considering neighbourhood form and physiography, ‘transit deserts’ are often located in areas that have a car-oriented design, have street layouts that are not conducive to public transport, and/or are older, historic areas with old and outdated infrastructure (if any at all). Additionally, many areas where ‘transit deserts’ are found have low population densities, as transit ridership would be too low to justify transit services in the area (Cameron, 2019). However, areas with adequate transit supply but a large, dense population have also been found to be ‘transit deserts’, as the demand significantly outweighs the supply (Jiao & Cai, 2020).

Another common characteristic of ‘transit deserts’ is difficulty in accessing the transit service. There is often a lack of adequate sidewalks and cycle lanes in ‘transit deserts’, making it difficult for users to access the service easily and safely (Jiao & Dillivan, 2013). Furthermore, ‘transit deserts’ are often found in areas where transit stops and stations are located on arterials, as it is difficult for users to access the service without travelling a considerable distance to the stop/station first (Cameron, 2019). As low-income populations are less likely to own private transport, 'transit deserts' are also often found in low-income areas, as these areas have a large transit dependent population (Allen, 2014; Newlands, 2020).

4.3.3.1 'Transit Desert' Analysis

Jiao and Dillivan (2013) were the first to develop a methodology to identify 'transit deserts'. This methodology involves a gap analysis – determining the gap between transit supply and demand – and using GIS to determine the location of transit deserts (areas with a large deficit in public transit supply).

To determine transit demand, the public transit-dependent population for each geographical unit in the study area is calculated, using Z-values to standardise the results. Z-values are numerical measurements used in statistics and involve the determination of a value's relationship to the average of a group of values, measured in terms of standard deviations from the mean (Heyes, 2019). To determine transit supply, several criteria addressing the physical components of public transit and the ability to access it were used to determine the public transit supply for each geographical unit. These criteria include the number of transit stops, frequency of transit service, and number of transit routes within the geographical unit (Jiao, 2017). Z-values were again used to standardise the results.

Finally, the transit demand Z-values were subtracted from the transit supply Z-values to determine if there was a transit gap or 'transit desert' (Cameron, 2019). A negative gap value (difference between demand and supply) indicated a deficit in transit supply (and potentially a 'transit desert'), while a positive gap value indicated a surplus (Jiao, 2017).

4.3.3.2 Adaptation to the South African Context

As the methodology developed by Jiao and Dillivan (2013) is specific to the US, Cameron (2019) and Vanderschuren et al. (2021) adapted it to fit the South African context. The 'transit desert' methodology modified by Cameron follows the same process as the original methodology, but has several different inputs and terms of reference. For example, when determining the transit-dependent population in South Africa, eligible household drivers were determined using the national driving age of 18, while in the US, this age is 16. Another significant change was the geographical unit used. Cameron used TAZs as opposed to block groups used by Jiao and Dillivan (Cameron, 2019).

Cameron used this adapted methodology to locate 'transit deserts' in Cape Town, only considering formal public transit supply (rail, conventional bus, and bus rapid transit (BRT)). Newlands (2020) added to Cameron's results by including paratransit (minibus taxis (MBT)) in the supply calculations, resulting in a comprehensive analysis of 'transit deserts' in Cape Town.

Figure 4.2 shows the results of Cameron's (2019) initial research that only considers formal public transit, and the results of Newlands' (2020) combined research including minibus taxis. Eighteen TAZs were analysed in Cape Town, with 10 TAZs classified as transit gaps (less severe than 'transit deserts', but still a lack of supply), four TAZs classified as having excess supply, and four TAZs classified as having adequate supply. Before the inclusion of minibus taxi supply, two 'transit deserts' were present, but due to the MBT inclusion, the severity of the supply deficit was reduced to change the classification of these TAZs to transit gaps (Vanderschuren et al., 2021).

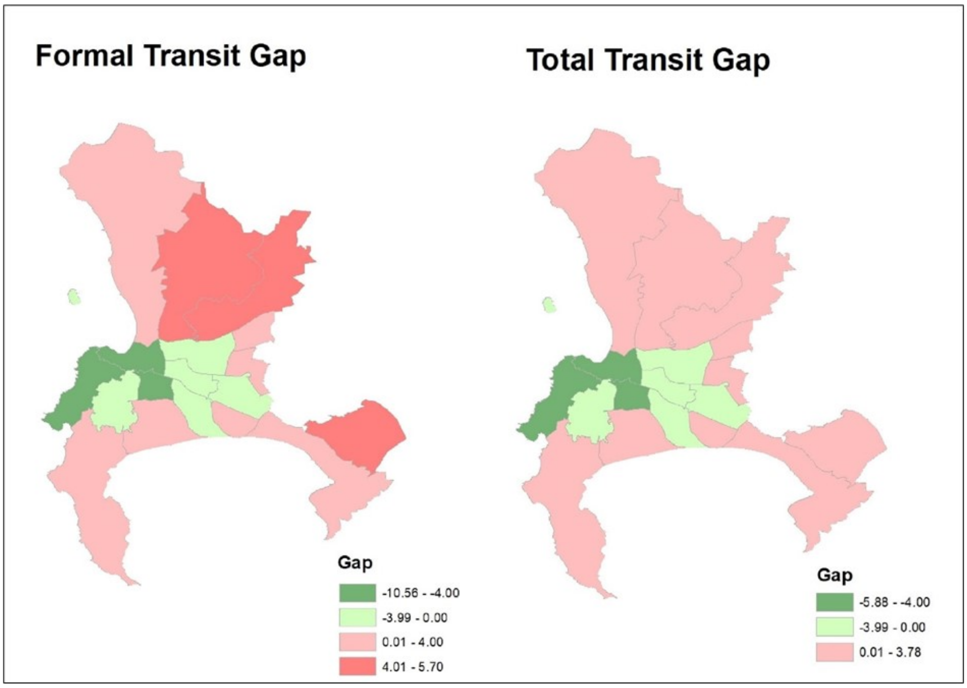


Figure 4.2: Formal and total public transit gap for Cape Town (Vanderschuren et al., 2021)

The results show that the areas with adequate and excess supply are located in and around the city centre, while areas with transit gaps (lack of supply) are located on the periphery of the city. This is consistent with 'transit desert' trends in other parts of the world. In the South African context, this is partly due to the discriminatory urban planning of Apartheid, where areas far away from the city with large portions of the commuter population have poor access to public transport (Vanderschuren et al., 2021).

Overall, the successful application of the 'transit desert' methodology in the South African context shows promise for further modifications of the method to different fields of study. Using the calculation principles from the 'transit desert' methodology, it is probable that a similar methodology for the field of road safety could be developed. This will be done in Section 4.6, after an explanation of the data and software requirements for this research, as well as a description of the case city used.

4.4 Data and Software

This section describes the data and software used in this research. Firstly, the data requirements for this study are identified and discussed. Next, the sources of these data are reviewed, followed by an explanation of the data's limitations. Finally, the software needed to process this data is described.

4.4.1 Data Requirements

The first step in creating a new methodology based on a novel concept (i.e., 'road safety deserts') is to identify what data is required. These data requirements were informed by the literature reviews on road safety assessment methodologies, the road safety status quo, and the 'desert' concept.

A key data requirement that can be inferred from the modified 'transit desert' methodology that was adapted to South Africa is the use of TAZs as the geographic unit of analysis. It is essential that all data needs to be at a disaggregated level, i.e., at a TAZ level, in order for comparison between different areas to occur. As this 'road safety desert' methodology is also being developed for the South African context, TAZs will be used for as the geographic unit of analysis.

Once the level of analysis was decided upon, the next step was to identify what road safety data at the disaggregated TAZ level would be required for this methodology. This data was informed by the literature review of road safety assessment methodologies and the road safety status quo. Arguably the most important road safety assessment indicator is the number of fatalities caused by road crashes. Fatality data at a disaggregated level was identified as a key data requirement for this research. Additionally, fatality data with associated infrastructure-related information (e.g., did the fatality occur in a built-up area?) was identified as important data for this methodology, as it would provide valuable insight into the road/environment factors that contributed to the fatalities. Finally, data showing fatalities per mode and modal share per area was deemed as important, as it would allow for an assessment of road safety for modes to be incorporated into the methodology.

4.4.2 Data Sources

The possibility of establishing 'road safety deserts' is dependent on data availability. Geo-coded fatality data for 2011-2015, including infrastructure-related information and fatalities per road user, was obtained from the Western Cape's Integrated Provincial Accident System (iPAS). Travel demand data per TAZ (i.e., road user distribution data per TAZ) was obtained from the 2013 National Household Travel Survey (NHTS), and the GIS TAZ shapefiles were obtained from the University of Cape Town. More recent NHTS data was collected in 2020. However, there is not a five-year safety data spread available yet that can be used as a comparison.

All data used in this research is secondary data, obtained from outside sources, such as iPAS and the NHTS. The use of this data was described in this study's research proposal, which was approved by University of Cape Town Ethics Committee (see Appendix B).

4.4.3 Data Limitations

The following are limitations of the data used in this research. These should be kept in mind when developing the methodology, analysing the results of the 'road safety desert' analysis, and in future iterations of the methodology:

- The most recent validated iPAS data available is for the 2011-2015 period (hence the use of 2013 NHTS data). Future applications of this methodology should aim to use the latest data available so that the results are more relevant.
- While fatality data is available at more disaggregated levels, travel demand data is only available at the TAZ level. This limits the analysis to the TAZ level, whereas a more disaggregated unit of analysis would give more accurate results.

- The fatality data in the iPAS system was geo-coded for the police stations where fatalities were recorded. These were manually sorted into the appropriate TAZs. However, the analysis would be more accurate if the fatalities were initially recorded at a TAZ level.

4.4.4 Software Requirements

The primary software used to store and sort the data was Microsoft Excel. Furthermore, all calculations occurred in Excel spreadsheets. The results of these calculations were analysed in Esri's ArcGIS software. This software was accessed through a licence provided by the University of Cape Town. ArcGIS was used to display the results of the analysis visually by creating maps of the driver, passenger, and pedestrian 'safety deserts'.

4.5 Case City Context

Based on data availability, specifically geo-coded information regarding fatalities from the iPAS database, the chosen case city for this research is the City of Cape Town. Once developed, the 'road safety desert' methodology will be applied to Cape Town to provide proof of concept.

Cape Town was the first permanent colonial settlement in South Africa, and is situated between the Atlantic Ocean and Table Mountain at the most southwestern tip of the African continent. It is the largest city in the Western Cape Province and the second-largest metropolitan area, by population size, in South Africa (COGTA, 2020). The City of Cape Town continues to expand rapidly, with contemporary growth estimated to be from 4 055 580 people in 2018 to an estimated 4 232 276 inhabitants in 2023 (Western Cape Government, 2017). Compared to other major cities, Cape Town has a relatively low average population density of 1 915 persons/km^2 (Western Cape Government, 2021). This density varies significantly within certain suburbs of Cape Town, with poorer areas often having much higher densities than wealthier areas (Vanderschuren et al., 2022). Figure 4.3 shows the study area disaggregated into sixteen TAZs.

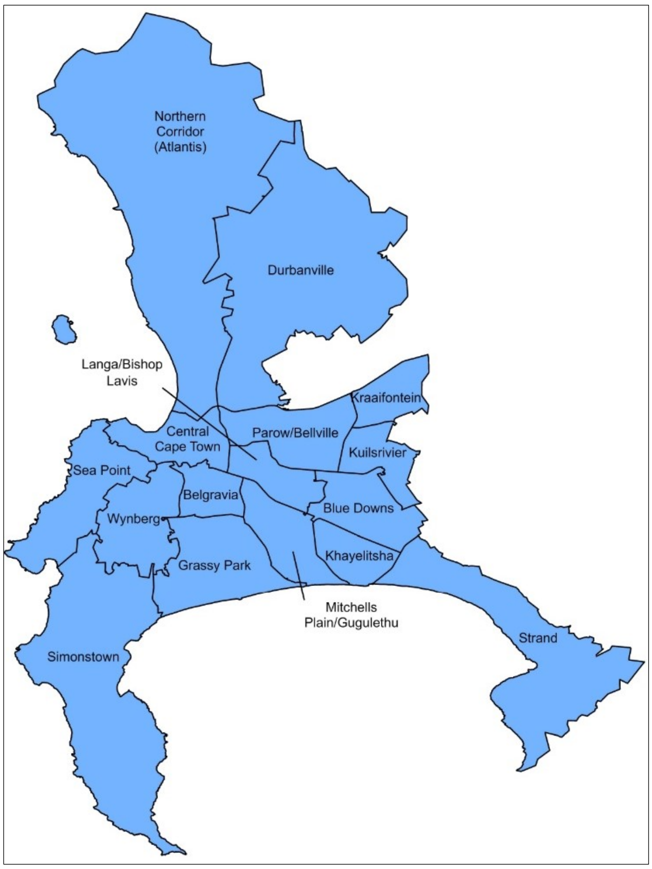


Figure 4.3: Transport analysis zones in Cape Town (Author's own image)

During a typical weekday morning peak period in Cape Town, 53% of trips are made by private vehicles, and 9% of trips are made by pedestrians and cyclists. Private vehicles are an important mode of transport in Cape Town, as they are the main mode used to travel to educational institutions and places of work (NHTS, 2014). Public transport trips make up 38% of trips and include rail, bus, BRT, and minibus taxis, which hold the largest public transport mode share in recent years; this mode has increased since the collapse of the rail system. Nearly all public transport trips are made by users in the low to low-middle income groups (Transport and Urban Development Authority, 2018). Public transport trips do include walking segments for the ingress and egress part of the trip, which are considered in this study.

The average annual fatality rate per 100 000 population in Cape Town is 26.4 fatalities in the 2011-2015 period, with approximately 58% of all fatalities being pedestrians (Vanderschuren et al., 2017c). Fatality numbers and rates differ between various TAZs (Figure 4.4). Fatality rates in four locations, namely Langa, Strand, Sea Point, and Belgravia, are low in absolute (average annual fatalities) and relative terms (average annual fatalities per 100 000 population), which is encouraging. Some areas, such as Kuilsrivier, Atlantis (Northern

Corridor), Grassy Park, Khayelitsha, and Mitchells Plain (MP)/Gugulethu, have relative fatality rates lower than the annual African average of 24.1 fatalities per 100 000 population, which are also positive results.

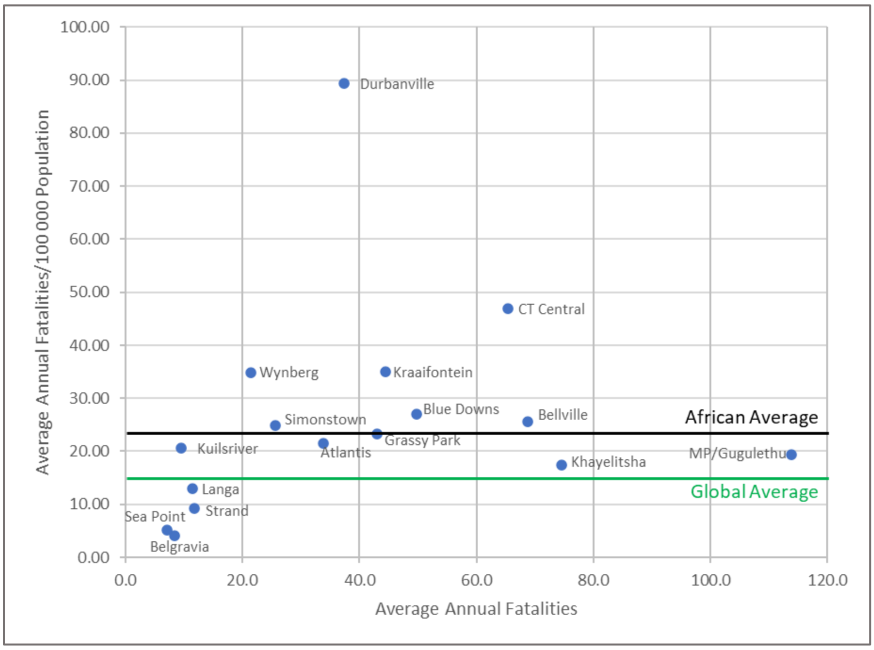


Figure 4.4: Average annual fatalities versus average annual fatalities per 100 000 population for TAZs in Cape Town (all modes) (Vanderschuren et al., 2017c based on CoCT FPL data 2011-2011)

However, some of these TAZs have high absolute fatalities (Atlantis (Northern Corridor), Grassy Park, Khayelitsha and MP/Gugulethu). Other areas have (much) higher fatality rates than the annual African average, with Durbanville being a clear negative outlier with almost 90 fatalities per 100 000 inhabitants annually. This could be due to a combination of high-speed corridors and limited pedestrian infrastructure in this TAZ.

As seen above, there are several areas with high absolute and/or relative fatality rates in Cape Town. This is a cause for concern. The application of the ‘road safety desert’ methodology to Cape Town aims to identify and verify which areas are most in need of intervention so that they can be prioritised in the implementation of road safety measures.

4.6 Methodology Development

This section will detail the development of the novel ‘road safety desert’ methodology, which is the primary aim of this research. A **‘road safety desert’** can be defined as **an area where there is a significantly higher road safety risk compared to the average road safety risk in the study area** in question. The development of this methodology was mainly informed by ‘transit deserts’, specifically the methodology adapted to the South African context. The results of the application of this methodology to the case city can be found in Chapter 5.

The principle of demand and supply is crucial to the ‘transit desert’ methodology (and the ‘desert’ concept as a whole), and it should, therefore, be considered in any new ‘desert’ methodologies. While the principle of demand and supply is not directly applicable to the field of road safety, the general principle is used in developing a ‘road safety desert’ methodology. Instead of using the demand values, safety values were used, and instead of using supply values, supply quality values were used. Together, these values enable the calculation of an overall ‘safety desert’ value, which represents the road safety risk of an area. These values will be described in detail below.

A further consideration when developing this methodology was to enable road safety assessment by road user type, i.e., to be able to identify ‘road safety deserts’ for different modes. In this study, motorised transport and non-motorised transport are considered, due to data availability. The methodology will be described for any mode *m,* with the purpose of demonstrating the calculation steps and identifying ‘safety deserts’ for any mode *m*. The methodology is applied in the same way for any mode (e.g., NMT values would be substituted for *m* values when determining NMT ‘safety deserts’ etc.).

Additionally, in the ‘transit desert’ methodology, the demand and supply values were absolute numbers, and, therefore, were corrected for TAZ size by dividing by the TAZ area. In this methodology, the supply quality and safety values use percentages that are comparable across areas. Therefore, these values do not need to be divided by the TAZ area.

4.6.1 Supply Quality Value

The first step in determining ‘road safety deserts’ is calculating the supply quality value. As noted in Section 3.2.3, road/environment factors are important to consider when assessing road fatalities, as these contribute to a significant number of road crashes. The supply quality value, *Q*, represents the quality of the road/environment-related infrastructure for each TAZ.

The supply quality score calculation is based on infrastructure-related information in the iPAS system. These infrastructure-related attributes correspond with those recorded in the database and give insight into the causes of these fatalities. The correlation levels of attributes were checked, and differences identified, hence, all relevant attributes were used. The infrastructure-related attributes used in this methodology are shown in Table 4.1. All attributes are classified into positive or negative cases in terms of road safety. For example, dry road surface is considered to be a positive case for road surface condition attribute, while wet, slippery roads are considered to be negative cases, as they increase the risk of a road crash. Similarly, speeds up to 30 km/h are considered to be safe (positive case), while speeds above this are considered unsafe (negative case).

Table 4.1: Infrastructure-related attributes used in the supply quality score calculation

ATTRIBUTE NUMBER	INFRASTRUCTURE ATTRIBUTE	POSITIVE CASES	NEGATIVE CASES
X_1	Built-up area	Yes	No
X_2	Junction type	Not at junction	Crossroads, staggered junction, circle, level crossing, off-ramp/slipway, on-ramp/slipway, pedestrian crossing, T-junction, Y-junction, property driveway/access
X_3	Light conditions	Daylight, night: lit by streetlight	Night: unlit, dawn/dusk
X_4	Obstructions	None	Accident site, roadworks, roadblock
X_5	Road alignment	Straight	Curving, sharp curve at 90 degrees
X_6	Road marking type	Barrier line, road sign	None
X_7	Road marking condition	Good	Not good
X_8	Road sign visibility	Yes	No
X_9	Road surface type	Tarmac	Concrete, gravel, dirt
X_{10}	Road surface quality	Good	Bumpy, cracks, potholes, corrugated
X_{11}	Road surface condition	Dry	Wet, ice, snow, slippery, loose gravel/sand, water: standing or moving, wet in areas
X_{12}	Road type	Single carriageway	Dual carriageway, freeway, one way, on/off ramp, off-road or on-road parking/rank
X_{13}	Speed	< 30 km/h	> 30 km/h

The total positive cases for each attribute are divided by the total number of cases for that attribute for the mode's fatalities. The results of these calculations for each attribute are summed together for each TAZ (Equation 5). In order to standardise for decimal places, the minimum total summed value out of all the TAZs is subtracted from the total summed value for each TAZ. This is then multiplied by 100 to get the overall mode supply quality value for each TAZ (Equation 6).

$$X_T = [(\frac{\sum X_{1p}}{\sum X_{1a}} + \frac{\sum X_{2p}}{\sum X_{2a}} + \cdots) \quad (5)$$

$$q_m = (X_T - X_{Tmin}) \times 100 \quad (6)$$

Where:

q_m = mode supply quality value

X_n = infrastructure attribute n

X_{np} = positive case of attribute n

X_{na} = all cases of attribute n

X_T = total summed value per TAZ

X_{Tmin} = minimum total summed value out of all the TAZs

Lastly, the mode supply quality value, q_m, is converted into a Z-value using Equation 7, resulting in the final overall mode supply quality value, Q_m, for each TAZ. This is done to standardise the criteria across the TAZs. A Z-value is a numerical measurement, used in statistics, where a value's relationship to the average of a group of values, measured in terms of standard deviations from the mean, is calculated. If a Z-value is 0, it indicates that the data point's score is identical to the mean score (Heyes, 2019).

$$Z = \frac{x-\mu}{\sigma} \quad (7)$$

Where:

Z = Z-value

x = value

μ = group mean

σ = standard deviation

4.6.2 Safety Value

The second step in determining 'road safety deserts' is calculating the safety value. The safety value, *S*, represents the number of fatalities per road user type for each TAZ (see Section 2.5.2. for more information on fatalities per mode as an assessment methodology).

Firstly, the demand for transport (measured in trips) is calculated for the mode. Trips per mode are obtained from the 2013 NHTS. The mode's demand is determined by comparing the number of trips made by the mode to the total number of trips in a TAZ (Equation 8). Secondly, mode safety, based on iPAS data, is calculated by dividing the mode's fatalities by the total number of fatalities in a TAZ (Equation 9). The overall mode safety value, s_m, is then determined by subtracting the mode's safety from the mode's demand (Equation 10).

$$mD = \frac{\sum T_m}{\sum T_a} \tag{8}$$

$$mS = \frac{\sum F_m}{\sum F_a} \tag{9}$$

$$s_M = mD - mS \tag{10}$$

Where:

mD = mode demand

mS = mode safety

T_m = number of trips per mode

T_a = number of total trips

F_m = number of fatalities per mode

F_a = number of total fatalities

s_M = mode safety value

Lastly, the mode safety value, s_m, is converted into a Z-value using Equation 7, resulting in the final overall mode safety value, S_m, for each TAZ.

4.6.3 Overall 'Safety Desert' Value

The final step in the 'road safety desert' methodology is to determine the overall 'safety desert' value, *O*. This value represents the road safety risk of a TAZ to the average person living in Cape Town.

Once the final supply quality and safety values have been calculated, the safety values are subtracted from the supply quality values for each TAZ, resulting in an overall mode 'safety desert' value. A positive overall 'safety desert' value indicates that there is a lower road safety risk than the risk for the average Capetonian (group value). A negative overall 'safety desert' value, on the other hand, reflects a less safe environment, i.e., a higher road safety risk.

$$O_m = Q_m - S_m \tag{11}$$

Where:

O_m = overall mode 'safety desert' value

Q_m = mode supply quality value

S_m = mode safety value

4.7 Résumé

This chapter set out to give a detailed description of the methodology followed in this research. The research framework was illustrated using a flow diagram, which outlined the key stages of the research project. This was followed by a thorough literature review of the 'desert' concept. The 'desert concept' assesses the equitable distribution of goods and services. In academic literature, a 'desert' is based on a comparison of supply and demand, which was first used to assess access to nutritious food. 'Food deserts' are defined as "those areas of cities where cheap, nutritious food is virtually unobtainable". 'Food desert' analyses, generally, use GIS mapping to identify areas that are more than a specified critical distance from a food shop (Clarke et al., 2002; Whelan et al., 2002; Wrigley et al., 2002).

'Transit deserts' were derived from the 'food desert' concept and originated when researching public transport services in the US. Transit deserts are "areas that lack adequate public transit service given areas containing populations that are deemed transit dependent". 'Transit desert' analysis involves determining the gap between transit supply and demand, and using GIS to determine the location of transit deserts (areas with a large deficit in public transit supply) (Jiao & Dillivan, 2013).

As the 'transit desert' methodology originated in the US, the methodology was modified to fit the South African context (Vanderschuren et al., 2021). The successful application of the ‘transit desert’ methodology in the South African context shows promise for further modifications of the method to different fields of study. It was concluded that, using the calculation principles from the ‘transit desert’ methodology, it is probable that a similar methodology for the field of road safety could be developed.

This conclusion led to the identification of data requirements for a ‘road safety desert’ methodology. The key data requirements for this study were fatality data, including infrastructure-related data and fatalities per road user, and road user distribution data, all at the disaggregate TAZ level. This data was sourced from iPAS (2011-1015) and the NHTS (2013). The limitations of the data were then discussed, followed by a description of the software requirements for this research (namely Microsoft Excel and Esri’s ArcGIS).

Once the data requirements had been identified, the case city could be selected. Due to data availability, Cape Town was chosen as the case city. The average annual fatality rate per 100 000 population in Cape Town is 26.4 fatalities in the 2011-2015 period, with approximately 58% of all fatalities being pedestrians. There are several TAZs within the city with high absolute and/or relative fatality rates, which is a cause for concern.

Finally, the ‘road safety desert’ methodology was developed. ‘Road safety deserts’ were defined as areas where there is a significantly higher road safety risk compared to the average road safety risk in the study area. Safety values (using fatalities per road user type) were subtracted from supply quality values (using infrastructure-related attributes) to determine an overall ‘safety desert’ value for each TAZ. This value represents the road safety risk of an area and can be calculated for different road user types. A positive overall ‘safety desert’ value indicates that there is a lower road safety risk than the risk for the average Capetonian, and vice versa.

The successful development of a ‘road safety desert’ methodology allows for the application of the methodology to Cape Town to provide proof of concept. This application aims to identify which areas are most in need of intervention so that they can be prioritised in the implementation of road safety measures. The results of this application can be found in the next chapter.

5. Results and Discussion

5.1 Introduction

Chapter 5 covers the results of the 'road safety desert' analysis for the case city. In the previous chapter, the 'road safety desert' methodology was developed. This chapter will detail the results of the application of this methodology to Cape Town in order to provide proof of concept. Firstly, the results of the supply quality value and safety value calculations for motorised transport (MT) will be presented, followed by the results of the motorised transport 'safety desert' analysis. Once the 'safety deserts' have been identified, a discussion of the results and the methodology's application will be given. This same process will then be followed for non-motorised transport (NMT). Finally, a summary of the chapter will be presented, and conclusions made.

5.2 Motorised Transport 'Safety Deserts'

This section presents the results of the 'road safety desert' methodology's application to Cape Town for motorised transport. In this study, motorised transport is defined quite broadly as consisting of vehicle drivers and passengers. This is due to data limitations: the data available in the iPAS database does not specify which modes these drivers and passengers form a part of (i.e., private cars, public transport etc.).

5.2.1 Supply Quality and Safety Values

The first step in determining 'road safety deserts' is to calculate the supply quality value for each TAZ. This value provides an indication of the quality of the road infrastructure in each TAZ in terms of road safety. As shown in Table 5.1 and Figure 5.2a, there are two TAZs with high quality supply for motorised transport ($Q_M > 0.75$), 11 TAZs with average supply quality ($-0.75 \leq Q_M \leq 0.75$), and three TAZs with poor quality supply ($Q_M < -0.75$). Durbanville has a supply quality value significantly higher than the other zones, which means that there is a significantly higher proportion of positive motorised transport infrastructure-related attributes in Durbanville. Conversely, Grassy Park has a supply quality significantly lower than other zones, which means that there is a very low proportion of positive infrastructure-related attributes present in the area.

Table 5.1: MT supply quality values

TAZ	SUPPLY QUALITY VALUE Q_M
Durbanville	1.89
Khayelitsha	0.79
Sea Point	0.75
Strand	0.69
Central Cape Town	0.61
Belgravia	0.57
Langa/Bishop Lavis	0.45
Northern Corridor	0.20
Mitchells Plain/Gugulethu	0.04
Parow/Bellville	-0.03
Simonstown	-0.03
Kuilsrivier	-0.27
Wynberg	-0.71
Kraaifontein	-0.85
Blue Downs	-1.84
Grassy Park	-2.26

Table 5.2: MT safety values

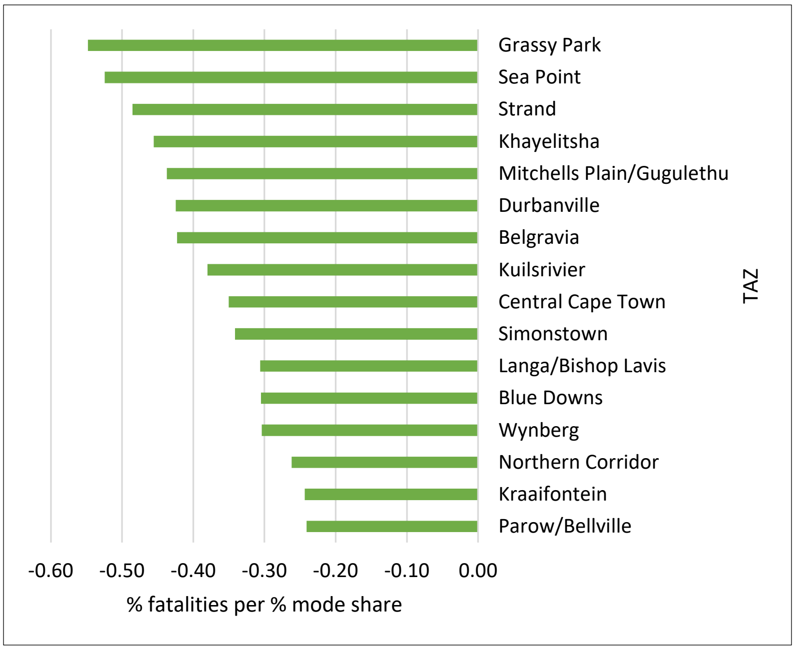
TAZ	SAFETY VALUE $-S_M$*
Grassy Park	1.80
Sea Point	1.55
Strand	1.14
Khayelitsha	0.83
Mitchells Plain/Gugulethu	0.63
Durbanville	0.50
Belgravia	0.48
Kuilsrivier	0.03
Central Cape Town	-0.28
Simonstown	-0.37
Langa/Bishop Lavis	-0.75
Blue Downs	-0.76
Wynberg	-0.77
Northern Corridor	-1.21
Kraaifontein	-1.41
Parow/Bellville	-1.43

* The values shown in this table are the safety values multiplied by -1 i.e., $-S$ for ease of understanding

The second step in determining ‘road safety deserts’ is to calculate the safety score per TAZ. The safety score consists of motorised transport demand and motorised transport safety. For demand, the percentage of motorised transport trips ranged from over 80% of all trips (Sea Point, Wynberg, the Northern Corridor, Simonstown, and Grassy Park) to 58% in Blue Downs. In terms of safety, motorised transport fatalities consisted of over 50% of all fatalities in the Northern Corridor and Wynberg, and just over 20% in the Strand.

Figure 5.1 shows the percentage fatalities per percentage mode share for each TAZ. All TAZs have a negative value, i.e., the percentage of fatalities is less than the percentage mode share, which is good. In Grassy Park and Sea Point, fatality rates are significantly lower than trip volumes, which shows that these areas are very safe for motorised transport. On the other hand, fatality rates in Kraaifontein and Parow/Bellville are only slightly lower than trip volumes. These findings are also reflected in Table 5.2 and Figure 5.2b, which show that four TAZs have a good safety value ($-S_M > 0.75$), seven have an average safety value ($-0.75 \leq -S_M \leq 0.75$), and five have a poor safety value ($-S_M < -0.75$) when compared to the other zones.

Figure 5.1: Percentage of MT fatalities per percentage MT mode share for each TAZ



5.2.2 Overall 'Safety Desert' Value

Once the supply quality and safety values were calculated, the overall 'safety desert' values could be determined, which led to the identification of 'road safety deserts' for motorised transport (Table 5.3 and Figure 5.2c). Five TAZs were identified as having a lower road safety risk than the risk for the average Capetonian, with two of these TAZs (Durbanville and Sea Point) having significantly lower road safety risk for motorised transport ($O_M > 2.00$). Six TAZs were found to have an average road safety risk when compared to other zones, and five TAZs were found to have a higher road safety risk than the risk for the average Capetonian. Blue Downs and Kraaifontein had significantly higher road safety risk ($O_M < -2.00$), which led to them being classified as motorised transport 'road safety deserts'.

Table 5.3: Overall MT 'safety desert' values

TAZ	'SAFETY DESERT' VALUE, O_M
Durbanville	2.39
Sea Point	2.30
Strand	1.83
Khayelitsha	1.62
Belgravia	1.06
Mitchells Plain/Gugulethu	0.67
Central Cape Town	0.33
Kuilsrivier	-0.24
Langa/Bishop Lavis	-0.30
Simonstown	-0.40
Grassy Park	-0.46
Northern Corridor	-1.01
Parow/Bellville	-1.46
Wynberg	-1.48
Kraaifontein	-2.26
Blue Downs	-2.60

5.2.3 Discussion of Motorised Transport Results

The motorised transport 'road safety desert' analysis resulted in the identification of two motorised transport 'road safety deserts', namely Kraaifontein and Blue Downs. The road safety risk in these areas is significantly higher than the risk to the average Capetonian. Kraaifontein and Blue Downs both have supply quality values and safety values well below average, which led to the overall safety risk being very high. These areas are both small, relatively dense, low- to middle-income towns on the periphery of Cape Town. Two TAZs, Durbanville and Sea Point, were identified as having a significantly lower road safety risk than the risk to the average Capetonian. These two TAZs are very different in location and size. Sea Point is located in the centre of the city and has a density of over four times that of Durbanville, which is located on the periphery of the city.

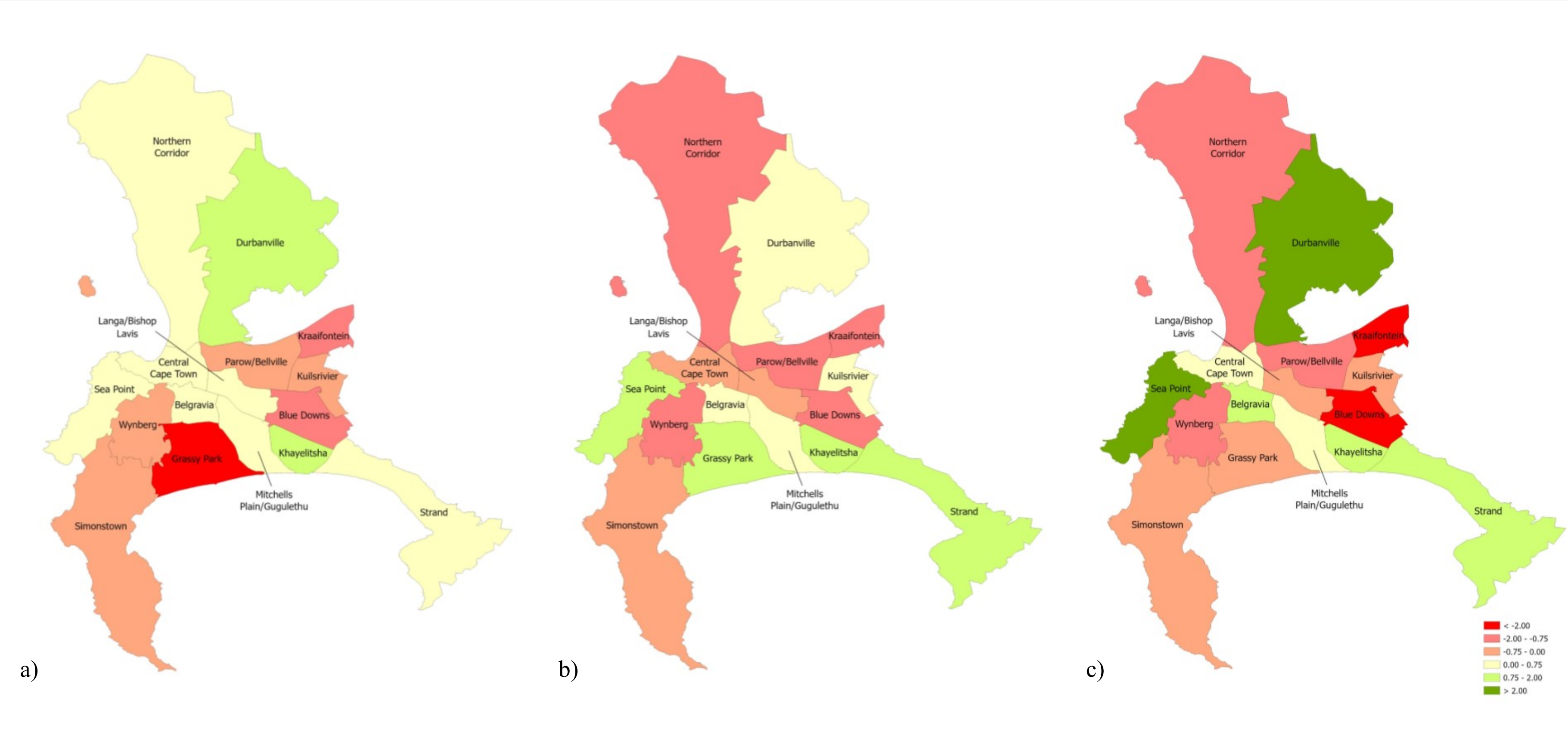


Figure 5.2: Maps showing the (L-R) a) supply quality values, b) safety values, and c) overall 'safety desert' values for MT per TAZ

Interestingly, Grassy Park was found to have the highest safety value but the lowest supply quality value in the study area. With a motorised transport mode share of 81% and a motorised transport fatality share of 26%, Grassy Park would seem to be a safe place for drivers and passengers. However, it also has the lowest supply quality score, meaning that it has the least amount of good quality road infrastructure. This discrepancy highlights the need for better supply quality data and smaller analysis zones. Currently, the supply quality value is based on a few locations within the TAZ where fatalities occur, i.e., the supply quality of a few locations is assumed to be the supply quality of the whole TAZ. Using smaller analysis zones would reduce the inaccuracy caused by this problem.

5.3 Non-Motorised Transport ‘Safety Deserts’

This section will present the results of the ‘road safety desert’ methodology’s application to Cape Town for non-motorised transport. In this study, non-motorised transport is defined as pedestrians and cyclists. However, cyclists make up less than 1% of entries in the iPAS database, so the vast majority of the data is pedestrian data.

5.3.1 Supply Quality and Safety Values

The NMT supply quality values for each TAZ were calculated first. As shown in Table 5.4 and Figure 5.4a, there are five TAZs with high quality supply for NMT ($Q_N > 0.75$), eight TAZs with average supply quality ($-0.75 \leq Q_N \leq 0.75$), and three TAZs with poor quality supply ($Q_N < -0.75$). Belgravia, Central Cape Town, and Simonstown have supply quality values significantly higher than the other zones, which means that there are a significantly higher proportion of positive NMT infrastructure-related attributes in these areas. Durbanville has a supply quality significantly lower than other zones, which means that there is a very low proportion of positive infrastructure-related attributes present in the area.

Table 5.4: NMT supply quality values

TAZ	SUPPLY QUALITY VALUE Q_N
Belgravia	1.16
Central Cape Town	1.16
Simonstown	1.16
Sea Point	0.91
Blue Downs	0.89
Parow/Bellville	0.72
Northern Corridor	0.28
Mitchells Plain/Gugulethu	0.13
Kraaifontein	0.00
Khayelitsha	-0.22
Langa/Bishop Lavis	-0.23
Kuilsrivier	-0.46
Strand	-0.50
Wynberg	-1.12
Grassy Park	-1.47
Durbanville	-2.40

Table 5.5: NMT safety values

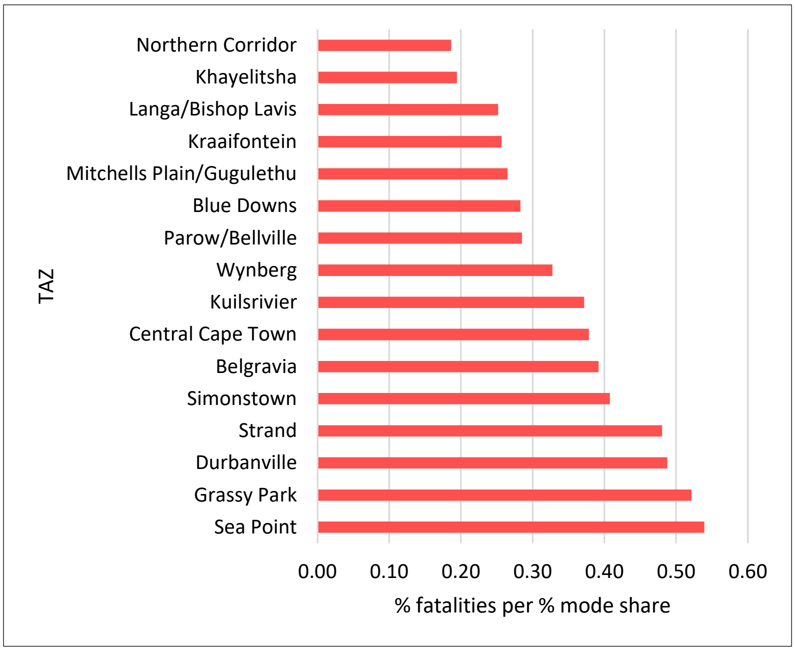
TAZ	SAFETY VALUE - S_N*
Northern Corridor	1.51
Khayelitsha	1.43
Langa/Bishop Lavis	0.91
Kraaifontein	0.87
Mitchells Plain/Gugulethu	0.79
Blue Downs	0.63
Parow/Bellville	0.61
Wynberg	0.22
Kuilsrivier	-0.18
Central Cape Town	-0.24
Belgravia	-0.36
Simonstown	-0.51
Strand	-1.17
Durbanville	-1.24
Grassy Park	-1.54
Sea Point	-1.71

* The values shown in this table are the safety values multiplied by -1 i.e., -*S* for ease of understanding

The NMT safety score per TAZ was then calculated. The safety score consists of NMT demand and NMT safety. For demand, the percentage of NMT trips ranged from over 45% of all trips in Khayelitsha and Mitchells Plain/Gugulethu, to 9% in Sea Point. In terms of safety, NMT fatalities consisted of nearly 80% of all fatalities in the Strand, and just over 40% in the Northern Corridor.

Figure 5.3 shows the percentage fatalities per percentage mode share for each TAZ. All TAZs have a positive value, i.e., the percentage fatalities are more than the percentage mode share, which means that there is a disproportionate amount of fatalities for the mode share. This shows that NMT users bear the burden of the road safety problem. In Grassy Park and Sea Point, fatality rates are significantly higher than trip volumes, which shows that these areas are very unsafe for NMT. On the other hand, fatality rates in the Northern Corridor and Khayelitsha are only slightly higher than trip volumes. These findings are also reflected in Table 5.5 and Figure 5.4b, which show that five TAZs have a good safety value ($-S_N > 0.75$), seven have an average safety value ($-0.75 \leq -S_N \leq 0.75$), and four have a poor safety value ($-S_N < -0.75$) when compared to the other zones.

Figure 5.3: Percentage NMT fatalities per percentage NMT mode share for each TAZ



5.3.2 Overall 'Safety Desert' Value

The overall 'safety desert' values were then determined, which led to the identification of 'road safety deserts' for NMT (Table 5.6 and Figure 5.4c). Eight TAZs were identified as having a lower road safety risk than the risk for the average Capetonian, while three TAZs were found to have an average road safety risk when compared to other zones. Five TAZs were found to have a higher road safety risk than the risk for the average Capetonian. Grassy Park and Sea Point had significantly higher road safety risk ($O_M < -2.00$), which led to them being classified as NMT 'road safety deserts'.

Table 5.6: Overall NMT 'safety desert' values

TAZ	'SAFETY DESERT' VALUE O_N
Northern Corridor	1.78
Blue Downs	1.52
Parow/Bellville	1.33
Khayelitsha	1.21
Central Cape Town	0.92
Mitchells Plain/Gugulethu	0.92
Kraaifontein	0.87
Belgravia	0.79
Langa/Bishop Lavis	0.68
Simonstown	0.65
Kuilsrivier	-0.64
Sea Point	-0.79
Wynberg	-0.90
Strand	-1.67
Grassy Park	-3.01
Durbanville	-3.64

5.3.3 Discussion of Non-Motorised Transport Results

The NMT 'road safety desert' analysis resulted in the identification of two NMT 'road safety deserts', namely Durbanville and Grassy Park. The road safety risk in these areas is significantly higher than the risk to the average Capetonian. Durbanville and Grassy Park both have supply quality values and safety values well below average, which led to the overall safety risk being very high.

While no TAZs were found to have a significantly lower road safety risk than the risk to the average Capetonian, Belgravia, Central Cape Town, and Simonstown had a slightly lower risk than other areas. Belgravia and Central Cape Town are both located in the centre of the city, while Simonstown is located on the periphery. These three TAZs have relatively poor safety values, i.e., a NMT fatality share greater than the NMT mode share, but were found to have an overall lower safety risk, due to the large amount of high-quality road infrastructure. This points again to the problem mentioned in Section 5.2.3, that the supply quality data needs to be improved and smaller analysis zones used.

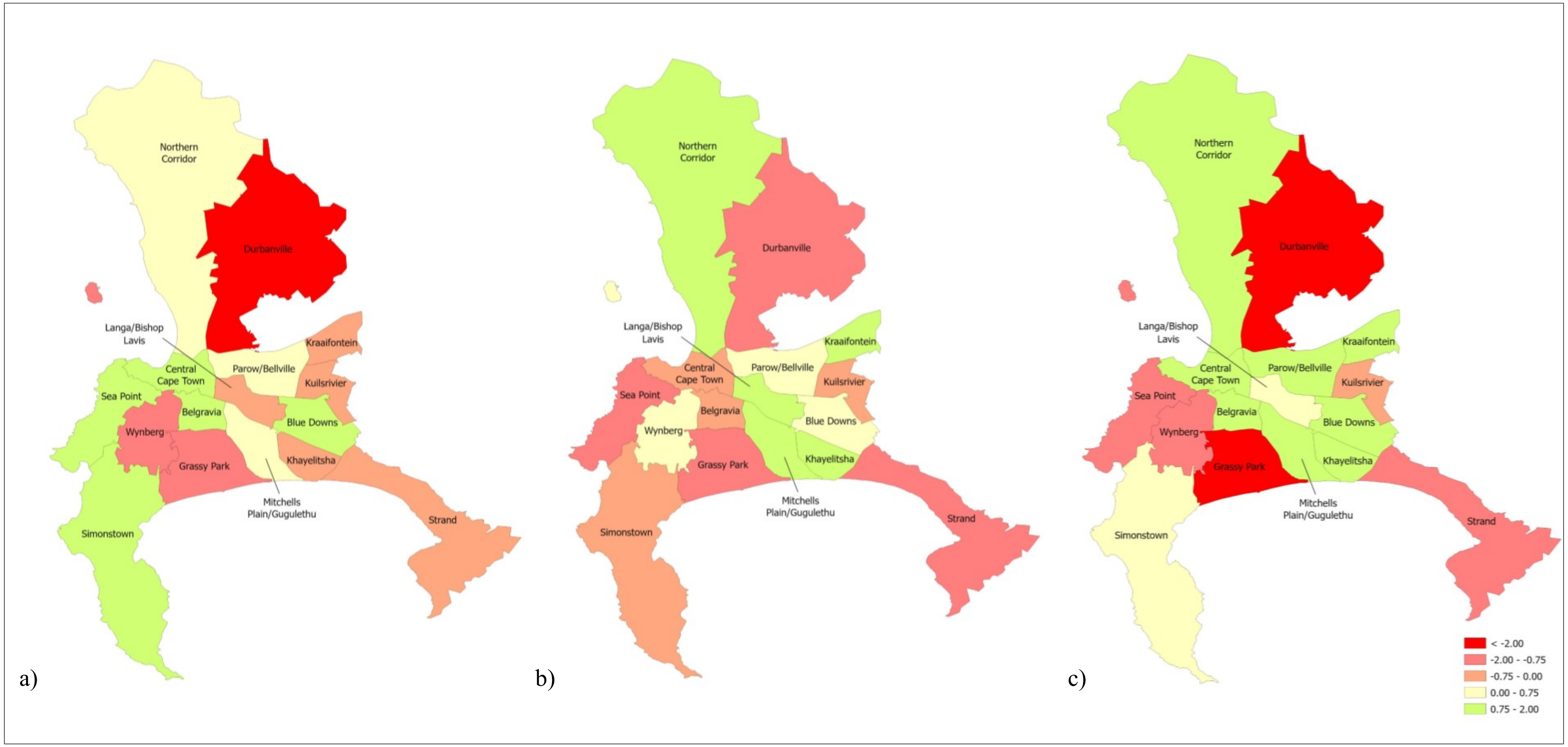


Figure 5.4: Maps showing the (L-R) a) supply quality values, b) safety values, and c) overall 'safety desert' values for NMT per TAZ

A further consideration in the NMT ‘road safety desert’ analysis is the fact that the supply quality data used is primarily relevant for motorised transport and not NMT. NMT-related infrastructure attributes, such as sidewalk length, number of pedestrian crossings, and the presence of traffic calming, were not available in the database, therefore, the supply quality attributes used do not give an accurate indication of the quality of NMT road infrastructure.

Additionally, the safety score calculations are based on trip making by residents, which causes inaccuracy in some TAZs’ results. For example, Sea Point has a NMT mode share of 9% and a fatality share of 63%, making it the TAZ with the worst safety score. However, in Sea Point, many non-residents use the area for recreational purposes. This is not captured by the NHTS demand data, which results in the findings being inaccurate. In reality, Sea Point has a much higher mode share, which, together with its good quality infrastructure, could result in it being an area with a lower overall safety risk.

5.4 Résumé

This chapter has presented the results of the ‘road safety desert’ analysis for motorised and non-motorised transport. For motorised transport, Kraaifontein and Blue Downs were identified as ‘road safety deserts’, i.e., having a road safety risk significantly higher than the risk to the average Capetonian. On the other hand, Durbanville and Sea Point were found to have a significantly lower road safety risk than the risk in other areas. For non-motorised transport, Durbanville and Grassy Park were found to be ‘road safety deserts’. Belgravia, Central Cape Town, and Simonstown were identified as having a slightly lower road safety risk than the risk to the average Capetonian.

The successful ‘road safety desert’ analysis of Cape Town provides proof of concept for this newly developed methodology. However, during the analysis of the results, a few issues presented themselves, primarily concerned with the data used in this research. The supply quality data needs to be improved and be specific to the mode being analysed. For example, when analysing NMT ‘safety deserts’, the infrastructure-related attributes should be NMT specific. Additionally, in areas where a large number of trips are made by non-residents, traffic counts rather than NHTS demand data (which is for residents’ trip making only) should be used in the safety value. A further consideration is the use of smaller analysis zones, which would increase the accuracy of the results.

Overall, these results prove that the ‘road safety desert’ methodology can be applied to a South African city successfully. While several issues did arise in the accuracy of the results, this is not inherently due to problems with the methodology, but due to problems with the data that was available to be used in this study.

6. Conclusion and Recommendations

This final chapter provides a consolidation of this research project and its findings. Firstly, the research question and objectives will be discussed individually, showing how each objective was met and how the research question was answered. Limitations of the study will then be discussed, along with recommendations of how these limitations can be overcome in future research.

6.1 Research Question and Objectives

This aim of this research was to answer the question, *"Can the 'desert' concept, used in the 'food desert' and 'transit desert' theories, be modified and applied to the field of road safety through the creation of a 'road safety desert' methodology?"* This question was answered through the completion of the following objectives:

Investigate global and local road safety conditions and fatality rates, as well as methodologies that are used to analyse and assess road safety and road fatalities.

Chapter 2 provided a comprehensive literature review of road safety assessment methodologies, which are important tools in measuring and understanding the road safety status quo of an area and identifying appropriate road safety interventions. The final outcomes of the road safety management system, i.e., the number of people killed and injured in road crashes, are assessed using road safety assessment methodologies (Koornstra et al., 2002). One common assessment methodology is hotspot analysis, which identifies hazardous locations and enables targeted infrastructure implementations to be carried out to improve the safety of each location (Shafabakhsh et al., 2017). Another important assessment methodology is fatality rates, which are used to meaningfully compare road safety across different regions or countries. The most commonly used fatality rate is road fatalities per 100 000 population (WHO, 2013; Kukić et al., 2016).

Other road safety assessment methodologies include road safety audits, network risk assessments, micro-simulation modelling, smartphone-based measurement systems, and fatalities per mode share (Mahmud et al., 2019). It is clear that there are many different road safety assessment methodologies that can be used to analyse and understand the road safety status quo of an area. However, while the current assessment methodologies provide informative and useful information about the state of road safety in a region, none of them have been able to make a radical difference in solving the road safety problem (as shown in Chapter 3).

Chapter 3 presented a review of the current road safety status quo at a global, regional, and local level. Globally, it was found that approximately 1.35 million road fatalities occur on the world's roads each year, and that the absolute number of road fatalities continues to increase (WHO, 2018). However, the global fatality rate has stabilised at 18 road fatalities per 100 000 population, which is encouraging progress (WHO, 2018). Vulnerable road users, such as pedestrians, cyclists, and children were found to bear the brunt of the road safety burden around the world. For example, in Africa, pedestrians account for 40% of all road fatalities. Africa has a fatality rate of 26.6 road fatalities per 100 000 population, which is significantly higher than the global average (WHO, 2018). Additionally, Africa has only 2% of the world's registered vehicles yet contributes to 20% of the world's road fatalities (Peden et al., 2013).

At a local level, South Africa was found to have a fatality rate of 21.3 road fatalities per 100 000 population, which is a significant reduction over the last two decades (RTMC, 2019; STATSSA, 2019). Despite this positive progress, road safety is still a serious problem in South Africa, with road fatalities costing approximately 3.5% of the country's GDP (ITF, 2019b). Additionally, 40.5% of all fatalities are pedestrians, with the majority of pedestrian fatalities forming part of the economically active population (RTMC, 2019). Overall, it can be seen that some encouraging progress is being made in reducing road fatalities, globally and locally. However, there are still far too many people dying every day globally (an average of 3 700 fatalities per day) and in South Africa (an average of 34 fatalities per day) (WHO, 2018; RTMC, 2019). Urgent intervention needs to be made in areas where nothing is being done, and continued, increased intervention needs to continue in areas where progress is being made.

Examine the 'desert' concept through understanding 'food deserts' and 'transit deserts', including their associated methodologies and applications.

Part of Chapter 4 consisted of a detailed literature review of the 'desert' concept. The 'desert concept' assesses the equitable distribution of goods and services. In academic literature, a 'desert' is based on a comparison of supply and demand, which was first used to assess access to nutritious food. 'Food deserts' are defined as "those areas of cities where cheap, nutritious food is virtually unobtainable". 'Food desert' analyses generally use GIS mapping to identify areas that are more than a specified critical distance from a food shop (Clarke et al., 2002; Whelan et al., 2002; Wrigley et al., 2002).

'Transit deserts' were derived from the 'food desert' concept and originated when researching public transport services in the US. Transit deserts are "areas that lack adequate public transit service given areas containing populations that are deemed transit dependent" (Jiao & Dillivan, 2013). 'Transit desert' analysis involves determining the gap between transit supply and demand, and using GIS to determine the location of transit deserts. As the 'transit desert' methodology originated in the US, the methodology was modified to fit the South African context (Vanderschuren et al., 2021). The successful application of the 'transit desert' methodology in the South African context shows promise for further modifications of the method to different fields of study, including the field of road safety.

Transfer the 'desert' concept to the field of road safety through the development of a 'road safety desert' methodology, which will include determining what data will be required as inputs to the methodology.

The main part of Chapter 4 detailed the development of the 'road safety desert' methodology. The key data requirements for the methodology were identified as fatality data, including infrastructure-related data and fatalities per road user, and road user distribution data, all at the disaggregate TAZ level. This data was sourced from iPAS (2011-2015) and the NHTS (2013). Due to data availability, Cape Town was chosen as the case city.

The 'road safety desert' methodology was developed using principles from the 'food desert' and 'transit desert' theories. **'Road safety deserts'** were defined as **areas where there is a**

significantly higher road safety risk compared to the average road safety risk in the study area. Safety values (using fatalities per road user type) were subtracted from supply quality values (using infrastructure-related attributes) to determine an overall 'safety desert' value for each TAZ. This value represents the road safety risk of an area and can be calculated for different road user types. A positive overall 'safety desert' value indicates that there is a lower road safety risk than the risk for the average Capetonian, and vice versa.

Apply this newly developed 'road safety desert' methodology to Cape Town in order to provide proof of concept and identify areas in the city where there is a high road safety risk.

The successful development of a 'road safety desert' methodology allowed for the application of the methodology to Cape Town to provide proof of concept. The results of this application were detailed in Chapter 5. Due to data availability, the analysis was conducted for motorised transport and non-motorised transport as opposed to individual modes. For motorised transport, Kraaifontein and Blue Downs were identified as 'road safety deserts', having a road safety risk significantly higher than the risk to the average Capetonian. On the other hand, Durbanville and Sea Point were found to have a significantly lower road safety risk than the risk in other areas. For NMT, Durbanville and Grassy Park were found to be 'road safety deserts'. Belgravia, Central Cape Town, and Simonstown were identified as having a slightly lower NMT road safety risk than the risk to the average Capetonian.

6.2 Research Limitations and Recommendations

This section will cover the final research objective, which includes the limitations of this research and recommendations for future research. The final research objective was to:

Assess whether the 'desert' concept was successfully applied to the field of road safety and identify where the methodology can be refined in future applications.

The successful 'road safety desert' analysis of Cape Town, as described in Chapter 5, provides proof of concept for this newly developed methodology. However, several issues did arise in the accuracy of the results. This is not inherently due to problems with the methodology, but due to problems with the data that was available to be used in this study. As said in Chapter 1, the road safety data and geospatial data used in this study is limited to what data has been collected by and is available from organisations and/or government. These data limitations affect the results of this research in several ways.

Firstly, the use of large analysis zones in the application of this methodology to the City of Cape Town resulted in somewhat cruder 'road safety desert' results. Large TAZs were used, due to data availability, but ideally smaller analysis zones should be used as they are more conducive to the identification of detailed action plans. In the South Africa context, it is recommended that efforts are made to identify how this disaggregated road safety information can be generated. Future applications of this methodology should make use of smaller analysis zones to improve the accuracy of the results.

Secondly, the supply quality data (i.e., data on infrastructure attributes related to road safety) was primarily relevant for motorised transport modes and not NMT modes. NMT-related infrastructure attributes, such as sidewalk length, number of pedestrian crossings, and the presence of traffic calming, were not available in the database, therefore, the supply quality attributes used do not give an accurate indication of the quality of NMT road infrastructure. It is recommended that future research identifies what indicators could be used to show the quality of pedestrian infrastructure, and that these indicators be used in the supply quality value calculations.

Additionally, data used in determining the demand for the safety value calculation should consider trip making by non-residents, especially in areas that have many non-residents using recreational facilities. Currently, the NHTS data used in this research only considered trip making by residents. Future research should make use of data that also considers trip making by non-residents, which could be obtained by traffic counts.

While this study only considered the broad grouping of motorised and non-motorised transport modes, due to data availability, future research should aim to perform the analysis for individual modes for greater accuracy. Furthermore, the methodology developed in this research only considers road fatalities. Future research into the inclusion of injuries and crash data in the methodology is warranted. It is important to note that this methodology only considers road/environment contributory factors and doesn't consider human and vehicle factors. This should be kept in mind when interpreting the results.

As seen in Chapter 2, when assessing road safety in the Western Cape based on absolute fatality numbers and fatality rates, different assessment methodologies sometimes give different results. Based on this variation in results, it is recommended that road safety analysis is conducted using a multitude of methods approach, mining the data to such an extent that an improved understanding is gained. The 'road safety desert' methodology developed in this study is an example of an assessment methodology that could be used in this multitude of methods approach.

Overall, it is recommended that other South African and international cities investigate the methodology developed in this study, and use it to identify areas and population groups that carry a high road safety burden. Through this analysis, a road safety strategy can be developed for the areas that need it most.

References

Acheson, D. 1998. Independent Inquiry into Inequalities in Health. London, United Kingdom: The Stationery Office.

Adminaité-Fodor, D. & Jost, G. 2019. Reducing speeding in Europe. Brussels, Belgium: ETSC.

African Development Bank (AfDB). 2013. Mortality in Africa: The Share of Road Traffic Fatalities. Abidjan, Cote d'Ivoire: AfDB.

Allen, D. 2014. Operating Within "Transit Deserts": The Application of Just, Open and Equitable Circulator Systems Within Outer Urban Residential Neighborhoods. Ph.D. Thesis. Morgan State University.

American Association of State Highway and Transportation Officials (AASHTO). 2009. *Highway Safety Manual.* Washington, D.C., United States: AASHTO.

Astarita, V., Guido, G. & Giofre, V.P. 2014. Co-operative ITS: Smartphone Based Measurement Systems for Road Safety Assessment. *Procedia Computer Science.* 37:404-409.

Babanoski, K., Ilijevski, I. & Dimovski, Z. 2016. Analysis of Road Traffic Safety Through Direct Relative Indicators for Traffic Accidents Fatality: Case of Republic of Macedonia. *Promet – Traffic&Transportation.* 28(6):661-669.

Beaumont, J., Lang, T., Leather, S. & Mucklow, C. 1995. Report From the Policy Sub-Group to The Nutrition Task Force: Low Income Project Team. Watford, United Kingdom: Institute of Grocery Distribution.

Behrens, R. 2002. Matching networks to needs: Travel needs and the configuration and management of local movement networks in South African cities. Ph.D. Thesis. University of Cape Town.

Behrens, R. & Makajuma, G. 2017. Pedestrian crossing behaviour in Cape Town and Nairobi: observations and implications. In *Non-Motorised Transport Integration into Urban Transport Planning in Africa.* W.V. Mitullah, M. Vanderschuren & M. Khayesi, Eds. Oxford, United Kingdom: Routledge.

Botha, G. & van der Walt, H. 2006. Fatal road crashes, contributory factors and the level of lawlessness. *25th Southern African Transport Conference.* 10-13 July 2006. Pretoria, South Africa. 377-387.

British Medical Journal (BMJ). 1973. Road Accidents Epidemic. *British Medical Journal*., 17:370–371.

Cameron, R. 2019. Identifying 'Transit Deserts' in a South African City – The Case of Cape Town. M.Phil. Dissertation. University of Cape Town.

Central Intelligence Agency (CIA). 2022. *The World Factbook: Field Listing – Roadways.* Available: https://www.cia.gov/the-world-factbook/field/roadways/ [2022, October].

CheckUP. 2013. Fact Sheet: Social Justice and Health. Australia: Health and Community Services Workforce Council.

Chepchieng, C.N., Gariy, A. & Josphat, M. 2016. Effects of Road Improvement on Safety: A Case Study of Nairobi-Thika Superhighway. *American Journal of Civil Engineering.* 3(6):199-206.

Choi, J., Kim, S., Kim, S., Hong, H. & Baik, S. 2013. Pedestrian crashes during jaywalking, can we afford to overlook? *16th Road Safety on Four Continents Conference.* 15-17 May 2013. Beijing, China.

Clarke, G., Eyre, H. & Guy, C. 2002. Deriving Indicators of Access to Food Retail Provision in British Cities: Studies of Cardiff, Leeds and Bradford. *Urban Studies.* 39(11):2041-2060.

Colak, H.E., Memisoglu, T., Erbas, Y.S. & Bediroglu, S. 2018. Hot spot analysis based on network spatial weights to determine spatial statistics of traffic accidents in Rize, Turkey. *Arabian Journal of Geosciences.* 11:151.

Constitution of the Republic of South Africa, Act 108 of 1996. *Government Gazette.* 11 October. Government Printer.

Davidovic, J., Pesic, D., Lipovac, K. & Antic, B. 2020. The Significance of the Development of Road Safety Performance Indicators Related to Driver Fatigue. *Transport Research Procedia.* 45:333-342.

Department of Co-operative Governance Traditional Affairs (COGTA). 2020. City of Cape Town Profile. Pretoria, South Africa,

Donkin, S.J.M., Dowler, E.A., Stevenson, S.J. & Turner, S.A. 1999. Mapping Access to Food at a Local Level. *British Food Journal.* 101:554-564.

Donkin, S.J.M., Dowler, E.A., Stevenson, S.J. & Turner, S.A. 2000. Mapping access to food in a deprived area: the development of price and availability indices. *Public Health Nutrition*. 3:31-38.

Economic Research Service (ERS). Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences. Washington, D.C., United States: United States Department of Agriculture.

Elvik, R. 1997. Evaluations of road accident blackspot treatment: a case of the iron law of evaluation studies? *Accident Analysis and Prevention.* 29:191-199.

Elvik, R. 2008. Road safety management by objectives: a critical analysis of the Norwegian approach. *Accident Analysis and Prevention.* 40:1115-1122.

Erdogan, S., Yilmaz, I., Baybura, T. & Gullu, M. 2008. Geographical information systems aided traffic accident analysis system case study: city of Afyonkarahisar. *Accident Analysis and Prevention*. 40(1):174-181.

European Transport Safety Council (ETSC). 2001. Transport Safety Performance Indicators. Brussels, Belgium: ETSC.

Farmer, C.M., Braitman, K.A. & Lund, A.K. 2010. Cell phone use while driving and attributable crash risk. *Traffic Injury Prevention*. 11(5):466-70.

Fawcett, L., Thorpe, N., Matthews, J. & Kremer, K. 2017. A novel Bayesian hierarchical model for road safety hotspot prediction. *Accident Analysis and Prevention*. 99:262-271.

Fell, J.C. & Voas, R.B. 2006. The effectiveness of reducing illegal blood alcohol concentration (BAC) limits for driving: Evidence for lowering the limit to .05 BAC. *Journal of Safety Research.* 37(3):233–43.

Finch, D.J., Kompfner, P., Lockwood, C.R. & Maycock, G. 1994. "Speed, speed limits and crashes". Project Record S211G/RB/Project Report PR 58. Berkshire, United Kingdom: Transport Research Laboratory.

Food Empowerment Project. N.d. *Food Deserts*. Available: https://foodispower.org/access-health/food-deserts/ [2022, October].

Gitelman, V., Doveh, E. & Hakkert, S. 2010. Designing a composite indicator for road safety. *Safety Science.* 48:1212-1224.

Gitelman, V., Vis, M., Weijermars, W. & Hakkert, S. 2014. Development of Road Safety Performance Indicators for the European Countries. *Advances in Social Sciences Research Journal.* 1(4):138-158.

Gregory, M. & Jarrett, D. 1994. The long-term analysis of accident remedial measures at high-risk sites in Essex. *Traffic Engineering & Control.* 35(1):8-11.

Grengs, J. 2001. Does public transit counteract the segregation of carless households? *Transportation Research Record*. 1753: 3-10.

Hakkert, S., Gitelman, V. & Vis, M. 2007. Road Safety Performance Indicators: Theory. Deliverable D3.6 of the EU FP6 project SafetyNet. Brussels, Belgium: Directorate-General Transport and Energy, European Commission.

Hauer, E. 1996. Identification of Sites with Promise. *Transportation Research Board:* 1542(1):54-60.

Hermans, E., Brijs, T. & Wets, G. 2008. *Developing a Theoretical Framework for Road Safety Performance Indicators and a Methodology for Creating a Performance Index.* University of Hasslet.

Heyes, A. 2019. *Z-Score Definition*. Available: https://www.investopedia.com/terms/z/zscore.asp [2022, October].

Hitge, G. & Vanderschuren, M. 2015. Comparison of travel time between private car and public transport in Cape Town. *Journal of the South Africa Institution of Civil Engineering*. 57(3).

Holló, P., Eksler, V. & Zukowska, J. 2010. Road safety performance indicators and their explanatory value: A critical view based on the experience of Central European countries. *Safety Science*. 48:1142-1150.

Hulchanski, J.D. 2010. The Three Cities Within Toronto: Income Polarization Among Toronto's Neighbourhoods, 1970 — 2005. Toronto, Canada: Cities Centre, University of Toronto.

International Transport Forum (ITF). 2019a. Road Safety Annual Report 2019. Paris, France: ITF.

ITF. 2019b. Road Safety Annual Report 2019: South Africa. Paris, France: ITF.

Jaehoon, S., Jun, L., Dong Su, K., Won Young, L., Jae Ick, S., Myohee, M., Eok, H. & Jae Kyung, L. 2014. Korea's 95% Reduction in Child Traffic Fatalities: Policies and Achievements. Republic of Korea: Korea Transport Institute.

Jiao, J. 2017. Identifying transit deserts in major Texas cities where the supplies missed the demands. *Journal of Transport and Land Use.* 10(1):528-540.

Jiao, J. & Dillivan, M. 2013. Transit Deserts: The Gap between Demand and Supply. *Journal of Public Transportation.* 16(3):23-39.

Jiao, J. & Cai, M. 2020. Using Open Source Data to Identify Transit Deserts in Four Major Chinese Cities. *International Journal of Geo-Information.* 9(100).

Jobanputra, R. 2013. An Investigation into The Reduction of Road Safety Risk in Cape Town Through the Use of Microscopic Simulation Modelling. Ph.D. Thesis. University of Cape Town.

Koornstra, M., Lynam, D., Nilsson, G., Noordzij, P., Pettersson, H.E., Wegman, F. & Wouters, P. 2002. A comparative study of the development of road safety in Sweden, the United Kingdom, and the Netherlands. Leidschendam, the Netherlands: Institute for Road Safety Research (SWOV).

Kukic, D., Lipovac, K., Pesic, D. & Rosic, M. 2016. The differences of road safety performance of countries based on outcome indicators. *Safety Science.* 89:279-287.

Labuschagne, F., de Beer, E., Roux, D. & Venter, K. 2017. The Cost of Crashes in South Africa 2016. *36th Southern African Transport Conference.* 10-13 July 2017. Pretoria, South Africa. 474-485.

Lamont, M. 2010. An epidemic on wheels? Road safety, public health and injury politics in Africa. *Anthropology Today.* 26(5):3-7.

Land Transport Safety Authority (LTSA). 2000. Road safety strategy 2010: A consultation document. Wellington, New Zealand: National Road Safety Committee, LTSA.

Levine, N. 2006. Houston, Texas, metropolitan traffic safety planning program. *Transportation Research Board.* 1969(1):92-100.

Mahmud, S.M., Ferreira, L., Hoque, Md.S. & Tavassoli, A. 2019. Micro-simulation modelling for traffic safety: A review and potential application to heterogeneous traffic environment. *IATSS Research.* 43:27-36.

Marta, D., Smart, W., Saffron, D., Hamilton, B. & Bhatnagar, Y. 2011. Road safety assessment methods: deciding which one to use. *Australasian Road Safety Research, Policing and Education Conference 2011.* 6-9 November 2011. Perth, Australia.

Meuleners, L.B., Hendrie, D., Lee, A.H. & Legge, M. 2008. Effectiveness of the Black Spot Programs in Western Australia. *Accident Analysis and Prevention.* 40:1211-1216.

Nantulya, V.M. & Reich, M.R. 2002. The neglected epidemic: road traffic injuries in developing countries. *British Medical Journal.* 324. 1139-41.

Newlands, A. 2020. Public Transit Deserts in Cape Town and How the Minibus Taxi Industry Fills the Gap. B.Sc. Eng. (Hons) Research Project. University of Cape Town.

Ojungu-Omara, I.P. & Vanderschuren, M. 2006. Ways of reducing accidents on South African roads. *25th Southern African Transport Conference.* 10-13 July 2006. Pretoria, South Africa. 454-464.

Organisation for Economic Co-Operation and Development (OECD). 2006. Speed Management. Paris, France: OECD.

Our World in Data. 2022. *Death rate from road injuries, 1990-2019.* Available: https://ourworldindata.org/grapher/death-rates-road-incidents?tab=chart [2022, September].

Pasanen, E. 1991. Driving speeds and pedestrian safety. Helsinki, Finland: Helsinki University.

Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A., Jarawan, E. & Mathers, C., Eds. 2004. World Report on Road Traffic Injury Prevention. Geneva, Switzerland: WHO.

Peden, M., Kobusingye, O. & Monono, M.E. 2013. Africa's roads – the deadliest in the world. *South African Medical Journal.* 103(4):228-229.

Road Traffic Management Corporation (RTMC). 2015. Road Traffic Report Calendar. Pretoria, South Africa: Department of Transport.

RTMC. 2016. Cost of Road Traffic Crashes in South Africa. Durban, South Africa. RTMC.

RTMC. 2019. State of Road Safety Report 2019. Pretoria, South Africa: Department of Transport.

Roadsafety.co.za. 2022. *Transport Month begins in South Africa in October*. Available: https://www.roadsafety.co.za/2022-10/transport-month-begins-in-south-africa-in-october/ [2023, February].

Ross, A., Jovanov, D., Vollpracht, H.J., Jasnic, S., Brancovic, R. & Viti, W. 2015. Regional Black Spot Management Guidelines. European Union Road Safety Project.

San Diego Foundation. 2016. *What is Corporate Philanthropy?* Available: https://www.sdfoundation.org/news-events/sdf-news/what-is-corporate-philanthropy/ [2022, September].

Shafabakhsh, G.A., Famili, A. & Bahadori, M.S. 2017. GIS-based spatial analysis of urban traffic accidents: Case study in Mashhad, Iran. *Journal of Traffic and Transportation Engineering (English Edition).* 4(3):290.

Social Exclusion Unit. 1998. Bringing Britain Together: A National Strategy for Neighbourhood Renewal. London, United Kingdom.

Statistics South Africa (STATSSA). 2014. National Households Travel Survey 2014. Pretoria, South Africa: STATSSA.

STATSSA. 2019. Mid-year population estimates. Pretoria, South Africa: STATSSA.

STATSSA. 2020. National Households Travel Survey 2020. Pretoria, South Africa: STATSSA.

Stigson, H., Krafft, M. & Tingvall, C. 2008. Use of Fatal Real-Life Crashes to Analyse a Safe Road Transport System Model, Including the Road User, the Vehicle, and the Road. *Traffic Injury Prevention.* 9(5):463-471.

Tešić, M., Hermans, E., Lipovac, K. & Pešić, D. 2018. Identifying the most significant indicators of the total road safety performance index. *Accident Analysis and Prevention.* 113:263-278.

Theofilatos, A., Folla, K., Laiou, A., Mavromatis, S. & Tannis, G. 2020. Identifying infrastructure risk factors in Africa. *Transportation Research Procedia.* 48:3163-3172.

Transport and Urban Development Authority. 2018. Comprehensive Integrated Transport Plan 2018-2013. Cape Town, South Africa: Transport and Urban Development Authority.

Trotta, M. 2016. What do we learn from GPS-data on road speeds? Behavioural measurement: speed outside urban areas 2015. Brussels, Belgium: : Belgian Road Safety Institute – Knowledge Centre Road Safety.

United Kingdom Department for Transport (UK DfT). 2015. Reported Road Casualties Great Britain: 2014 Annual Report. London, United Kingdom: Department for Transport.

United States Department of Transport (US DoT). 2018. Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey. Washington, D.C., United States: National Highway Traffic Safety Administration, Department of Transport.

Vanderschuren, M. 2006. Intelligent Transport Systems for South Africa Impact Assessment Through Microscopic Simulation in the South African Context. Ph.D. Thesis. University of Cape Town.

Vanderschuren, M., Phayane, S., Sinclair, M. & Janmohammed, A. 2017a. Development of a Road Safety Implementation Programme for the Western Cape: Safety Implementation Framework – Main Document. Cape Town, South Africa: Department of Transport and Public Works, Western Cape Government.

Vanderschuren, M., Phayane, S., Sinclair, M. & Janmohammed, A. 2017b. Development of a Road Safety Implementation Programme for the Western Cape: Safety Implementation Framework – West Coast. Cape Town, South Africa: Department of Transport and Public Works, Western Cape Government.

Vanderschuren, M., Phayane, S., Sinclair, M. & Janmohammed, A. 2017c. Development of a Road Safety Implementation Programme for the Western Cape: Safety Implementation Framework – Cape Town. Cape Town, South Africa: Department of Transport and Public Works, Western Cape Government.

Vanderschuren, M., Janmohammed, A., Phayane, S. & Arendse, M. 2018. GIS Identification of Hazardous Locations in the Western Cape. *37th Southern African Transport Conference.* 9-12 July 2018. Pretoria, South Africa. 532-545.

Vanderschuren, M. & Roux, D. 2019. Road safety comparison in South Africa – how do the different provinces compare? *Southern African Transport Conference.* Pretoria, South Africa.

Vanderschuren, M., Arendse, M., Lane-Visser, T. & Janmohammed, A. 2020. Combatting the Road Safety Burden in the Developing World: The Case of South Africa. *Transportation Research Procedia.* 48:1174-1184.

Vanderschuren, M., Cameron, R., Newlands, A. & Schalekamp, H. 2021. Geographical Modelling of Transit Deserts in Cape Town. *Sustainability.*13(997).

Vanderschuren, M., Newlands, A. & Wheeldon, A. 2022. Improving Non-Motorized Transportation Provision in a Socially Inclusive Way—the Case of Cape Town. *Frontiers in Sustainable Cities.* 4:775339.

Verster, T. & Fourie, E. 2018. The good, the bad and the ugly of South African fatal road accidents. *South African Journal of Science.* 114(7/8).

Vis, M. 2005. *Deliverable D3.1: State of the art Report on Road Safety Performance Indicators.* European Commission, Directorate-General Transport and Energy.

Vissers, L., Houwing, S. & Wegman, F. 2018. Alcohol-related road casualties in official crash statistics. ITF.

Wegman, F. & Oppe, S. 2010. Benchmarking road safety performances of countries. *Safety Science.* 48:1203-1211.

Western Cape Government. 2017. City of Cape Town Socio-Economic Profile 2017. Cape Town, South Africa: Western Cape Government.

Western Cape Government. 2021. City of Cape Town Socio-Economic Profile 2017. Cape Town, South Africa: Western Cape Government.

Whelan, A., Wrigley, N., Warm, D. & Cannings, E. 2002. Life in a 'Food Desert'. *Urban Studies.* 39(11):2083-2100.

Whitehead, M. 1998. Food deserts: what's in a name? *Health Education Journal* 57:189-190.

World Health Organisation (WHO). 2009. Global Status Report on Road Safety Summary 2009. Geneva, Switzerland: WHO.

WHO. 2013. Global Status Report on Road Safety 2013: supporting a decade of action. Geneva, Switzerland: WHO.

WHO. 2016. Road Safety in the African Region 2015. Geneva, Switzerland: WHO.

WHO. 2018. Global Status Report on Road Safety 2018. Geneva, Switzerland: WHO.

WHO. 2021. *Estimated road traffic death rate (per 100 000 population).* Available: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/estimated-road-traffic-death-rate-(per-100-000-population) [2022, September].

WHO. 2022. *New political declaration to halve road traffic deaths and injuries by 2030 is a milestone achievement.* Available: https://www.who.int/news/item/30-06-2022-new-political-declaration-to-halve-road-traffic-deaths-and-injuries-by-2030-is-a-milestone-achievement [2022, September].

World Road Association (PIARC). N.d. *9.2 General principles of infrastructure safety management.* Available: https://roadsafety.piarc.org/en/planning-design-operation-infrastructure-management/general-principles [2022, September].

Wrigley, N. 2002. ‘Food Deserts' in British Cities: Policy Context and Research Priorities. *Urban Studies.* 39(11):2029-2040.

Wrigley, N., Warm, D., Margetts, B. & Whelan, A. 2002. Assessing the Impact of Improved Retail Access on Diet in a ‘Food Desert': A Preliminary Report. *Urban Studies.* 39(11):2061-2082.

Yan, W. & Job, S. 2021. *Road crashes affect women and men differently—here's why.* Available: https://blogs.worldbank.org/endpovertyinsouthasia/road-crashes-affect-women-and-men-differently-heres-why [2022, September].

Zahran, E.M.M., Tan, S.J., Tan, E.H.A., Putra, N.A.A.B.M.A., Yap, Y.H. & Rahman, E.K.A. 2021. Spatial analysis of road traffic accident hotspots: evaluation and validation of recent approaches using road safety audit. *Journal of Transportation Safety & Security.* 13(6):575-604.

Appendix A: Data for 'Road Safety Desert' Calculations

Table A1: TAZ area size

TAZ	AREA SIZE (km^2)
Belgravia	34
Blue Downs	59
Central Cape Town	53
Durbanville	349
Grassy Park	83
Khayelitsha	38
Kraaifontein	39
Kuilsrivier	41
Langa/Bishop Lavis	40
Mitchells Plain/Gugulethu	55
Northern Corridor	462
Parow/Bellville	74
Sea Point	33
Simonstown	55
Strand	110
Wynberg	71

Table A2: Motorised transport supply quality calculation values

TAZ	BUILT-UP AREA	JUNCTION TYPE	LIGHT CONDITIONS	OBSTRUCTIONS	ROAD DIRECTION	ROAD MARKING CONDITION	ROAD MARKING TYPE	ROAD SIGN VISIBILITY
Belgravia	0.94595	0.32432	0.94595	0.67568	0.64865	0.78378	0.81081	0.89189
Blue Downs	0.88889	0.44444	0.55556	0.81481	0.85185	0.81481	0.85185	0.74074
Central Cape Town	0.95588	0.38235	0.87500	0.86029	0.63971	0.88235	0.72794	0.91176
Durbanville	0.92500	0.37500	0.82500	0.85000	0.75000	0.90000	0.85000	0.90000
Grassy Park	0.95455	0.25000	0.72727	0.79545	0.68182	0.88636	0.77273	0.75000
Khayelitsha	1.00000	0.32609	0.78261	0.60870	0.80435	0.89130	0.82609	0.93478
Kraaifontein	0.82143	0.44444	0.75000	0.81481	0.89286	0.82143	0.85714	0.89286
Kuilsrivier	0.98276	0.25862	0.65517	0.84483	0.77586	0.84483	0.65517	0.84483
Langa/Bishop Lavis	0.98000	0.32000	0.76000	0.74000	0.76000	0.76000	0.88000	0.80000
Mitchells Plain/Gugulethu	0.97059	0.36471	0.80000	0.77059	0.87059	0.81176	0.75294	0.85882
Northern Corridor	0.97241	0.35172	0.77241	0.82069	0.80000	0.77931	0.71724	0.77931
Parow/Bellville	0.95930	0.39535	0.79651	0.86628	0.79651	0.81395	0.76744	0.85465
Sea Point	1.00000	0.48276	0.86207	0.79310	0.65517	0.72414	0.72414	0.86207
Simonstown	0.96078	0.47059	0.58824	0.84314	0.60784	0.80392	0.82353	0.86275
Strand	0.97619	0.47619	0.75000	0.77381	0.65476	0.82143	0.83333	0.85714
Wynberg	0.98889	0.31111	0.87778	0.75556	0.62222	0.78889	0.76667	0.86667

Table A2 continued: Motorised transport supply quality calculation values

TAZ	ROAD SURFACE CONDITIONS	ROAD SURFACE QUALITY	ROAD SURFACE TYPE	ROAD TYPE	SPEED LIMIT	TOTAL	FINAL	SUPPLY QUALITY VALUE Q_M
Belgravia	0.91892	0.97297	0.91892	0.22727	0.53571	9.60	68.28	0.57
Blue Downs	0.74074	0.92593	0.88889	0.35897	0.14286	9.02	10.23	-1.84
Central Cape Town	0.88971	0.94118	0.92647	0.15108	0.46602	9.61	69.17	0.61
Durbanville	0.87500	0.87500	0.95000	0.41176	0.46429	9.95	100.00	1.89
Grassy Park	0.75000	0.86364	0.84091	0.30159	0.34375	8.92	0.00	-2.26
Khayelitsha	0.82609	0.93478	0.89130	0.33898	0.48718	9.65	73.42	0.79
Kraaifontein	0.75000	0.89286	0.85714	0.17647	0.28571	9.26	33.91	-0.85
Kuilsrivier	0.75862	0.96552	0.91379	0.29688	0.60000	9.40	47.88	-0.27
Langa/Bishop Lavis	0.82000	0.89796	0.96000	0.28333	0.60976	9.57	65.30	0.45
Mitchells Plain/Gugulethu	0.78824	0.91765	0.88235	0.29949	0.38356	9.47	55.32	0.04
Northern Corridor	0.82759	0.91034	0.94483	0.29947	0.53571	9.51	59.30	0.20
Parow/Bellville	0.80233	0.94186	0.93023	0.19577	0.33594	9.46	53.81	-0.03
Sea Point	0.82759	0.86207	0.93103	0.30952	0.60870	9.64	72.43	0.75
Simonstown	0.84314	0.94118	0.96078	0.36486	0.38462	9.46	53.73	-0.03
Strand	0.78571	0.94048	0.92857	0.29000	0.54098	9.63	71.05	0.69
Wynberg	0.74444	0.88889	0.91111	0.22449	0.54545	9.29	37.41	-0.71

Table A3: Motorised transport safety calculation values

TAZ	% FATALITIES	% MODE SHARE	ROAD SAFETY - MODEL SPLIT (RISK)	SAFETY VALUE S_M
Belgravia	37.1%	79.4%	-0.42	-0.48
Blue Downs	28.0%	58.5%	-0.31	0.76
Central Cape Town	41.7%	76.7%	-0.35	0.28
Durbanville	37.4%	79.9%	-0.42	-0.50
Grassy Park	26.1%	80.9%	-0.55	-1.80
Khayelitsha	29.0%	74.5%	-0.46	-0.83
Kraaifontein	40.2%	64.6%	-0.24	1.41
Kuilsrivier	37.9%	76.0%	-0.38	-0.03
Langa/Bishop Lavis	36.1%	66.7%	-0.31	0.75
Mitchells Plain/Gugulethu	26.3%	70.0%	-0.44	-0.63
Northern Corridor	59.4%	85.6%	-0.26	1.21
Parow/Bellville	44.6%	68.7%	-0.24	1.43
Sea Point	36.7%	89.2%	-0.52	-1.55
Simonstown	49.1%	83.3%	-0.34	0.37
Strand	21.7%	70.3%	-0.49	-1.14
Wynberg	56.0%	86.4%	-0.30	0.77

Table A4: Non-motorised transport supply quality calculation values

TAZ	BUILT-UP AREA	JUNCTION TYPE	LIGHT CONDITIONS	OBSTRUCTIONS	ROAD DIRECTION	ROAD MARKING CONDITION	ROAD MARKING TYPE	ROAD SIGN VISIBILITY
Belgravia	1.00000	0.40000	0.88571	0.65714	0.80000	0.82857	0.77143	0.82857
Blue Downs	0.96721	0.68852	0.77049	0.40984	0.91803	0.80328	0.70492	0.72131
Central Cape Town	0.93258	0.42697	0.85393	0.59551	0.85393	0.83146	0.73034	0.95506
Durbanville	0.91667	0.45833	0.66667	0.54167	0.66667	0.58333	0.75000	0.62500
Grassy Park	0.93827	0.50617	0.70370	0.48148	0.76543	0.70370	0.70370	0.76543
Khayelitsha	0.97661	0.53216	0.72515	0.54971	0.81287	0.74269	0.74269	0.75439
Kraaifontein	0.83333	0.66667	0.83333	0.27778	0.94444	1.00000	0.83333	0.88889
Kuilsrivier	1.00000	0.28571	0.56122	0.76531	0.91837	0.71429	0.77551	0.80612
Langa/Bishop Lavis	0.98876	0.44944	0.75281	0.60674	0.84270	0.75281	0.73034	0.78652
Mitchells Plain/Gugulethu	0.94802	0.40099	0.77475	0.55693	0.82921	0.80693	0.69059	0.80446
Northern Corridor	0.97619	0.41270	0.67460	0.59524	0.85714	0.80952	0.76190	0.75397
Parow/Bellville	0.97183	0.44131	0.74178	0.62911	0.84507	0.86385	0.81221	0.89202
Sea Point	1.00000	0.50000	0.81250	0.81250	0.87500	0.62500	0.68750	0.81250
Simonstown	0.90909	0.57576	0.90909	0.69697	0.90909	0.81818	0.72727	0.75758
Strand	0.97297	0.40541	0.67568	0.54054	0.78378	0.82432	0.72973	0.77027
Wynberg	0.94286	0.51429	0.71429	0.65714	0.68571	0.80000	0.68571	0.77143

Table A4 continued: Non-motorised transport supply quality calculation values

TAZ	ROAD SURFACE CONDITIONS	ROAD SURFACE QUALITY	ROAD SURFACE TYPE	ROAD TYPE	SPEED LIMIT	TOTAL	FINAL	SUPPLY QUALITY VALUE Q_N
Belgravia	0.91429	0.85714	0.94286	0.31429	0.462	9.66	100.00	0.91
Blue Downs	0.88525	0.93443	0.98361	0.55738	0.160	9.50	92.58	0.89
Central Cape Town	0.88764	0.91011	0.94382	0.28090	0.411	9.61	100.00	0.89
Durbanville	0.75000	0.79167	0.83333	0.58333	0.412	8.58	0.00	0.75
Grassy Park	0.76543	0.80247	0.87654	0.48148	0.347	8.84	26.23	0.77
Khayelitsha	0.79532	0.86550	0.87135	0.52632	0.295	9.19	61.18	0.80
Kraaifontein	0.77778	0.94444	1.00000	0.11111	0.143	9.25	67.55	0.78
Kuilsrivier	0.84694	0.88776	0.86735	0.23469	0.462	9.12	54.64	0.85
Langa/Bishop Lavis	0.80899	0.79775	0.88764	0.33708	0.448	9.19	61.09	0.81
Mitchells Plain/Gugulethu	0.87624	0.92822	0.89604	0.41089	0.365	9.29	71.03	0.88
Northern Corridor	0.80952	0.92857	0.92063	0.38095	0.451	9.33	75.31	0.81
Parow/Bellville	0.86385	0.94366	0.95305	0.16901	0.329	9.46	87.71	0.86
Sea Point	0.68750	0.93750	1.00000	0.37500	0.385	9.51	93.12	0.69
Simonstown	0.96970	0.96970	0.87879	0.63636	0.310	10.07	100.00	0.97
Strand	0.83784	0.86486	0.87838	0.39189	0.436	9.11	53.36	0.84
Wynberg	0.74286	0.85714	0.82857	0.25714	0.481	8.94	36.02	0.74

Table A5: Non-motorised transport safety calculation values

TAZ	% FATALITIES	% MODE SHARE	ROAD SAFETY - MODEL SPLIT (RISK)	SAFETY VALUE S_N
Belgravia	62.9%	23.7%	0.39	0.36
Blue Downs	72.0%	43.7%	0.28	-0.63
Central Cape Town	58.3%	20.5%	0.38	0.24
Durbanville	62.6%	13.8%	0.49	1.24
Grassy Park	73.9%	21.8%	0.52	1.54
Khayelitsha	71.0%	51.6%	0.19	-1.43
Kraaifontein	59.8%	34.1%	0.26	-0.87
Kuilsrivier	62.1%	24.9%	0.37	0.18
Langa/Bishop Lavis	63.9%	38.7%	0.25	-0.91
Mitchells Plain/Gugulethu	73.7%	47.2%	0.26	-0.79
Northern Corridor	40.6%	21.9%	0.19	-1.51
Parow/Bellville	55.4%	26.9%	0.29	-0.61
Sea Point	63.3%	9.3%	0.54	1.71
Simonstown	50.9%	10.1%	0.41	0.51
Strand	78.3%	30.2%	0.48	1.17
Wynberg	44.0%	11.2%	0.33	-0.22

Appendix B: Ethics Clearance

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

ETHICS APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		ALEXANDRA NEWLANDS
Department		CIVIL ENGINEERING
Preferred email address of applicant:		NWLALE001@MYUCT.AC.ZA
If Student	Your Degree: e.g., MSc, PhD, etc.	MSc. CIVIL ENGINEERING
	Credit Value of Research: e.g., 60/120/180/360 etc.	120
	Name of Supervisor (if supervised):	PROF. MARIANNE VANDERSCHUREN
If this is a research contract, indicate the source of funding/sponsorship		/
Project Title		DEVELOPING A ROAD SAFETY DESERT METHODOLOGY FOR SOUTH AFRICA

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	ALEXANDRA NEWLANDS		25/04/2022
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Marianne Vanderschuren		25/04/2022

APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).	Prof. Alphose Zingoni		12/05/2022