THE DEVELOPMENT OF ROAD SAFETY ASSESSMENT SCREENING PROCEDURES FOR THE CITY OF TSHWANE METROPOLITAN MUNICIPALITY

BY

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DECLARATION

This dissertation, except where indicated in the text, is the candidate's own work and has not been submitted in part, or in whole, at any other University or University of Technology.

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ABSTRACT

The word “accident” is a familiar term used to describe a collision involving one or more transportation vehicles that results in property damage, injury or death. The term implies a random event that occurs due to no specific reason other than human error or unforeseen circumstances. The American National Highway Traffic Safety Administration (NHTSA) suggests replacing the word “accident” with “crash” as the word “crash” implies that the collision could have been prevented or minimised by improving driver behaviour, vehicle design, roadway geometry or the environment (Garber and Hoel 2015: 150). In the global context, South Africa, as is characteristic of many developing countries with limited resources, faces the challenge to proactively managing, reducing and eliminating the high incidence of road crashes, injuries and fatalities. Due to an absence of routine Road Safety Assessment and Audit procedures within the relevant departments at the City of Tshwane Metropolitan Municipality (CTMM), the main aim of this research was to develop procedures with measurable benefits which would promote a safer road environment. The data analysis and findings describe statistically significant relationships between Average Daily Traffic (ADT) as the independent variable and Accident Frequency as the dependant variable. The linear regression models and equations as developed allowed for the prediction of crash rates and the prioritisation of CTMM road safety projects. The findings indicated significant increases in accident rates on higher order roads (typically traffic signalled controlled intersections) with factors such as a greater number of intersection conflict points, greater pedestrian volumes and increased intersection saturation or volume/capacity levels contributing to higher accident rates. Intersection controls and traffic safety measures such as traffic circles, traffic signals, and traffic signs were assessed for effectiveness in reducing the Rate of Accidents per Million of Entering Vehicles (RMEVs). The research highlights the vulnerability of Non-Motorised Transport (NMT) (particularly pedestrians) which contributed to approximately 40% of all accident fatalities (Department of Transport 2016: 31). The recommendation therefore is for a road safety assessment and screening process to focus and allocate greater resources in the effort to proactively reduce the number of pedestrian fatalities.

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LIST OF ACRONYMS

ADT	- Average Daily Traffic
ARF	- Accident Report Form
ANOVA	- Analysis of Variance
BCR	- Benefit-Cost Ratio
CBD	- Central Business District
COTO	- Committee of Transport Officials
CITP	- Comprehensive Integrated Transport Plan
CTMM	- City of Tshwane Metropolitan Municipality
DV	- Dependent Variable
EAN	- Equivalent Accident Number
EB	- Empirical Bayes
EPDO	- Equivalent Property Damage Only
ESD	- Emergency Services Department
ETA	- eThekwini Transport Authority
FHWA	- Federal Highway Association
GDP	- Gross Domestic Product
HSM	- Highway Safety Manual
ISO	- International Organization for Standardization
ISRSR	- In-service Road Safety Review
IV	- Independent Variable
LOS	- Level of Service
LOSS	- Level of Service of Safety
NHTSA	- National Highway Traffic Safety Administration
NLTA	- National Land Transport Act 5 of 2009
NMT	- Non-Motorised Transport
NPV	- Net Present Value
NRSS	- National Road Safety Strategy
RAF	- Road Accident Fund
RMEV	- Rate of Accidents per Million of Entering Vehicles
RMVK	- Rate per 100 Million Vehicle Kilometres
RSA	- Road Safety Audit

RTMC	- Road Traffic Management Corporation
SABS	- South African Bureau of Standards
SANRAL	- South African National Roads Agency Limited
SANTACO	- South African National Taxi Council
SAPS	- South African Police Service
SARSAM	- South African Road Safety Audit Manual
SPF	- Safety Performance Function
SPSS	- Statistical Package for the Social Sciences
STA	- Site Traffic Assessment
TIA	- Traffic Impact Assessment
TMH	- Technical Methods for Highways
TRAFMAN	- Traffic Authority Management Information System
TRH	- Technical Recommendations for Highways
TMPD	- Tshwane Metro Police Department
UNDA	- United Nations Decade of Action
UTG	- Urban Transport Guidelines
WHO	- World Health Organisation

CHAPTER 1: INTRODUCTION

1.1 Background of the study

The City of Tshwane Metropolitan Municipality's (CTMM's) response to road safety challenges is partially addressed on a strategic level in its Comprehensive Integrated Transport Plan (City of Tshwane 2015: 15-5), with its goal described as being to "Improve the safety and security of the transport system". However, on an operational or functional level, a need exists to shift from a reactive to a proactive management of road accidents and for the development of practical, measurable and results focused road safety assessment and audit procedures within the CTMM.

The theoretical framework for this study range from the current South African best practice document for Road Safety Audits (RSAs) namely, the South African Road Safety Audit Manual (SARSAM), to international standards such as the American Highway Safety Manual (HSM), which provide the framework and extensive methodologies required to assess and manage road safety. The South African standards need to be contextualised in the framework of the larger body of international standards and research. The problem of the generalisation of differing standards and research settings can be illustrated by the applicability of the HSM to South African conditions, which was found to be generally unreliable (Roodt 2012: 502). The lack of correlation with South African studies may be due to various factors, such as different driving cultures, vehicle fleets and poor data quality. The CTMM further acknowledges statistics provided by the Road Traffic Management Corporation (RTMC) that indicate that pedestrians account for approximately 40 % of all road fatalities in South Africa (Department of Transport 2016: 31). A holistic systems approach is proposed to address road safety and the range of factors that expose pedestrians to risk, such as human error, inappropriate vehicle speed, poor road design, and the inadequate enforcement of traffic regulations (World Health Organization [WHO] 2013: 9).

1.2 Problem statement

The research problem was defined as "The absence of routine Road Safety Assessment and screening procedures within the responsible CTMM departments has a severely negative effect on the safety of road users within the City of Tshwane, even though the need for an effective Road Safety Audit policy is described in the Comprehensive Integrated Transport Plan (City of Tshwane 2015: 15-5)."

The associated research questions included:

- What is the status quo in terms of the resources and gaps within the CTMM, influencing the development of cost-effective road safety screening procedures?
- What are the best practice methods for the identification, screening and mitigation of accident hotspots in the CTMM?
- What is the benchmark risk for each Intersection Control type in terms of the Rate of accidents likely to occur per Million of Entering Vehicles (RMEVs)?
- How effective are traffic impact studies and road design services provided by professional engineers in the development of safe roads?
- What is the relationship between Level of Service (LOS) and Rate of accidents per Million of Entering Vehicles (RMEVs)?

1.3 Research aims and objectives

The aim was the development of routine Road Safety Assessment and screening procedures within the CTMM Roads and Stormwater Department in order to promote a safer road user environment. These procedures will pave the way for the eventual development of more comprehensive Road Safety Audit procedures that are supported by adequate financial and human resources within the CTMM.

To achieve the general research aim, it was hypothesised that:

- The utilisation of current resources within the CTMM for the completion of basic Road Safety Assessments for accident hotspots, and the development of remedial measures and infrastructure can result in the reduction of accidents.

- Traffic Impact studies, LOS, road designs and safety measures can be evaluated via before-and-after studies in order to assess their efficacy in the development of safer roads.
- Screening procedures taking into account accident frequency, traffic volumes and the benchmarking of risks can result in cost effective RSAs.
- Any gaps in the efficacy of procedures can be effectively addressed by short term plans with current CTMM resources as well as medium to long term plans with future resources.

The broader aim of the study while focusing on road safety screening measures on the macro level, is as per international standards and guidelines, dependent on traffic volumes as a quantitative tool in order to develop an effective network screening method. It is due to the relationship of network screening and traffic volumes that the specific research objectives, namely the null hypothesis and alternate hypothesis, were set out as follows:

$H_{0\ (null)}$: Traffic volume per intersection control type does not affect traffic accidents. The slope coefficient of traffic volume is zero.

$H_{a\ (alternative)}$: Traffic volume per intersection control type does affect traffic accidents. The slope coefficient of traffic volume is positive.

1.4 Research methodology

A quantitative research methodology was proposed due to planned numerical and measurable data samples that lend themselves to statistical analysis. The primary sources of data used were, the type of intersection control implemented, geographic information systems (ARCGIS), the CTMM traffic count databases, the Metro Police Traffic Authority Management Information System (TRAFMAN) accident database as well as new traffic counts where required. The statistical model appropriate to this study was the least square Linear Regression Model (Rakha et al. 2010: 21). Similarly, if accident databases are found to have many observations with no observed accidents, zero-inflated Poisson and negative binomial regressions are proposed, to account for the multitude of zeros by splitting roadways into two separate states, that is either a zero state or a normal count state (Mannering and Bhat 2014: 7). Intersection controls and traffic safety measures such as traffic circles, traffic signals, traffic signs and road markings were assessed for effectiveness in reducing the Rate of Accidents per Million of Entering Vehicles (RMEVs).

The key variables analysed were:

- The intersection, traffic control measures.
- The frequency of accidents in terms of the number of accidents per year.
- The Rate of accidents per Million of Entering Vehicles (RMEVs).
- The traffic counts (exposure) as Average Daily Traffic (ADT).

The analysis of CTMM records, databases and geographic information systems (ARCGIS) allowed various intersection control types to be benchmarked and ranked according to road safety performance. The study resulted in the determination of average RMEVs per intersection control type as well as linear regression equations for the prediction of accident rates.

1.5 Contribution to the current state of knowledge

The benchmarking of the RMEVs per intersection control type will assist in developing a screening procedure to identify specific roads within the CTMM road network that can be termed as accident hotspots. The identification of accident hotspots will enable the CTMM to prioritise limited budgets, and direct Road Safety Assessments and Audits in a cost-effective manner to where it will yield the most benefits in the reduction of accidents.

1.6 Research limitations

The geographical limitations of the research study were within the boundaries of the CTMM which totals 6 368 km² and extends approximately 121 km from east to west and 108 km from north to south making it the third-largest city in the world in terms of land area. The study can however be easily generalised and applicable to any other road network within South Africa. The South African Road Safety Audit Manual (Road Traffic Management Corporation, 2012: 8) describes the 5 E Model of road safety which is Education, Engineering, Enforcement, Emergency Response and Evaluation. The scope of this study will be limited to the two Es of Engineering and Evaluation.

1.7 Overview of chapters

A summary overview of the chapters of this study are presented below:

Chapter 1 - Introduction and Background

This chapter describes the problem statement, the objectives, scope of the study and contribution to the current state of knowledge.

Chapter 2 - Literature Review

The literature review includes subheadings on road safety engineering, the cause of road accidents, role of human factors in accidents, effect of road classification on accidents, effect of road geometry and design, RSAs, the status quo of road safety assessment in the South African context and internationally, the availability of accident data and countermeasures that support safer roads.

Chapter 3 - Methodology

This chapter includes evaluation and selection of statistical methods appropriate per research question, research design, and limitations.

Chapter 4 - Data Analysis and Findings

This chapter includes the parameters to be tested, graphical summary of findings in tables and charts and discussion of the findings.

Chapter 5 - Conclusion

This chapter presents the conclusion regarding whether the results confirm the hypothesis, assessment of alternatives to the problem and comparison of the results to current research.

Chapter 6 - Recommendations

This chapter presents the actions or steps to be taken, the resources required and proposed future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The South African road fatality rate, as a middle-income country, is reported to be 23.5 fatalities per 100 000 population, which is notably higher than the 2015 WHO Global status report on road safety, which indicates the world-wide average for middle-income countries as being 18.4 fatalities per 100 000 population (Road Traffic Management Corporation 2018:12).

The Road Safety Strategy for the CTMM is described in its CITP. The legal mandate for the preparation of the CITP is outlined in the National Land Transport Act 5 of 2009 (NLTA). The CITP describes the multi-faceted nature of road safety and a need for better coordination between the various role-players. The challenge is to develop a holistic strategy that makes the best use of limited funds and further resources, including the Tshwane Metro Police Department (TMPD), the Emergency Services Department (ESD), the Traffic Engineering and Operations section, the TRAFMAN accident database and road user education campaigns.

One of the first known pedestrian fatalities was recorded in 1896 when United Kingdom citizen Bridget Driscoll was killed when she inadvertently walked into the path of a moving car (Goniewicz et al. 2015: 174). The earliest British legislation to include aspects on road safety was the Motor Car Act 1903, which included regulations on speed limits and braking abilities of vehicles. While road transportation for the present-day scenario is an aggregation of the technological progress of aspects such as road materials, vehicles, infrastructure and design standards, the challenge of road safety issues endures. As a starting point for road safety in the South African context, a framework is provided by legislation in the form of the National Road Traffic Act (No. 93 of 1996). While there is sufficient road safety literature in the form of engineering standards and manuals, such as the Technical Recommendations for Highways (TRH17), Technical Methods for Highways (TMH16), Urban Transport Guidelines (UTG1), South African National Roads Agency Geometric Design Guidelines, International Organization for Standardization - ISO 39001 and the South African Road Safety Audit Manual (SARSAM), the unfortunate status quo is that the vast majority of new and existing roads in South Africa are not subjected to any RSAs as per SARSAM requirements. In terms of international literature, a premier standard is presented by the Highway Safety Manual (HSM), which provides comprehensive guidance in terms of human factors and the fundamentals of traffic safety, quantitative crash prediction methods and the roadway safety process including network screening methods. The HSM describes numerous network screening methods including crash frequency, crash rate, equivalent property damage only, relative severity index, critical rate, excessive predicted average crash frequency, level of service of safety and crash frequency with Empirical Bayes adjustment (Garber and Hoel 2015: 183).

The institutional constraints experienced by road authorities for the implementation of RSAs and assessments, include a lack of capacity, funding, time limitations, lack of support and inadequate training (Grosskopf, Labuschagne and Moyana 2010: 3). In addition, road safety and the development of effective countermeasures for road traffic crashes are negatively affected by deficient databases and data-gathering processes in South Africa (Mynhardt 2014: 563). Road safety and Level of Service (LOS) within the South African context require further exploration in terms of international research which indicates that accident rates are almost constant for volume to capacity (v/c) ratios up to 0.65 (i.e. for LOS A, LOS B and LOS C), and a considerable increase of accident rates is related to v/c ratios approaching 1.0 (Valdivia 2009: 8). The concept of nominal and substantive safety describes shortcomings in the application of design standards, where the design engineer assumes that meeting design manual requirements equals safety. Road safety issues, however, usually present themselves only after newly built roads are open to traffic operations, when the disparity between design standards, nominal safety, substantive safety and accident hotspots reveal the shortcomings in the simplistic reliance on standards as a means to ensure safe roads (Milton 2012: 6).

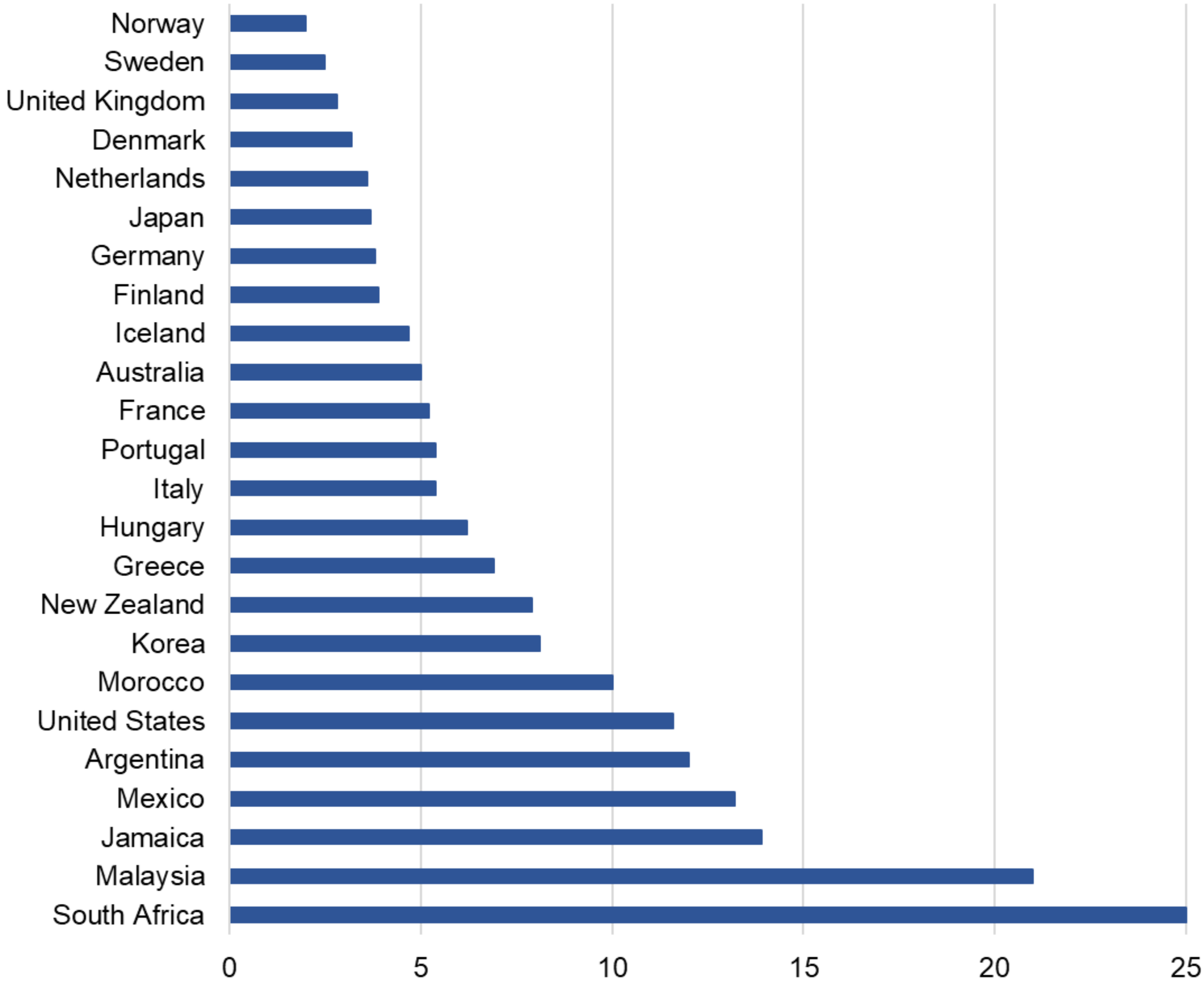

Figure 2.1: Road fatalities per 100 000 inhabitants
Source: International Transport Forum (2018: 56)

The global rate for road crash fatalities is 17.4 per 100 000 population, with the highest rates being in the African region and other low and middle-income countries, such as South Africa (WHO 2015: 5). South Africa has a very high rate of road fatalities of 25 per 100 000 inhabitants as per Figure 2.1 above, pointing to the need for greater research and interventions in road safety.

2.2 Status quo of road safety at the City of Tshwane

The Department of Transport National Road Safety Strategy (NRSS) (2016-2030) is based on the United Nations Decade of Action (UNDA) for Road Safety 2011-2020. The five pillars of the UNDA road safety strategy (and the scope of this research report) are shown in Figure 2.2 below. The UNDA and the NRSS provide a basis and guideline for the implementation of all road safety programmes, including that of the CTMM. The CTMM Road Safety Strategy encompasses various functional departments to ensure a holistic strategy aligned to the UNDA for Road Safety 2011-2020.

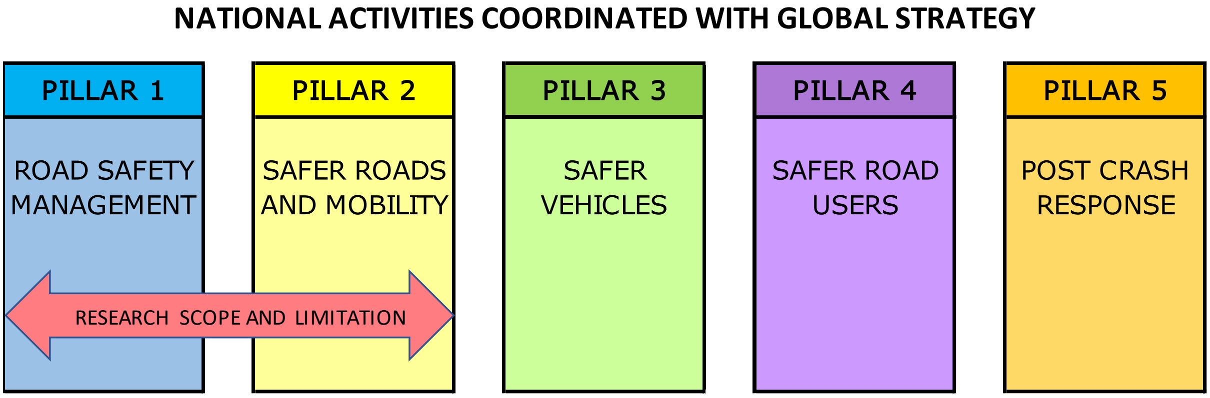

Figure 2.2: United Nations Decade of Action for Road Safety 2011-2020
Source: Adapted from, City of Tshwane (2015: 14-2)

The scope of this research study is represented as per the overlay with the UNDA for road safety shown in Figure 2.2 above. The Tshwane Road Safety Management Strategy involves various role players as represented in Table 2.1 below and includes the Department of Transport and Roads: Traffic Engineering & Operations section (TEO), the Tshwane Metro Police Department (TMPD), the Emergency Services Department (ESD), the Gauteng Department of Community Safety, the South African National Roads Agency (SANRAL), the Road Traffic Management Corporation (RTMC), the South African Police Service (SAPS), the South African National Taxi Council (SANTACO) and the Road Accident Fund (RAF).

Table 2.1: CTMM road safety stakeholders

STAKEHOLDER ROLES AND RESPONSIBILITIES
Traffic Engineering & Operations section (TEO)
• Development and Management of the CTMM Road Safety Master Plan • Annual updated traffic calming priority list
Tshwane Metro Police Department (TMPD)
• Secure a safe road environment following the pro-active principle “broken window approach” • Accident on-scene management, capturing of accident data and preparation of basic reports
Emergency Services Department (ESD)
• Establishment of an Interdepartmental Joint Operation Committee (JOC) to mitigate against ten major disaster risks of the city
Gauteng Department of Community Safety
• Tasks are to monitor policing agencies, implement crime prevention initiatives, manage traffic, educate citizens about public safety
South African National Roads Agency (SANRAL)
• Involvement relates to infrastructure, road-user behaviour and post-crash response • Development of the Netsafe road safety risk tool • Provision of road safety education at schools that are within 5km of the SANRAL road network
Road Traffic Management Corporation (RTMC)
• Partnership with International Road Assessment Programme to conduct road assessments and recommend remedial actions • Testing of the Crash Information Management System to improve accuracy of accident data
South African Police Service (SAPS)
• Implementation of an effective Integrated Justice System Programme particularly with respect to information management
South African National Taxi Council (SANTACO)
• The taxi industry adopted the TR3 2020 Strategy which amongst others, addresses road safety
Road Accident Fund (RAF)
• The key objectives of the RAF Road Safety Strategy are to reduce the current high rate of road accidents by becoming proactively involved in activities aimed at addressing road safety behaviour and promoting road safety principles and effective law enforcement
INTERLINKED STAKEHOLDER CHALLENGES
• Lack of implementation on Road Safety Audits at local government level • Accident statistics suffer from under reporting problems, adequate analysis and quality of data and lack of functional reporting structure • Educational and training material for school learners outdated • Lack of dedicated Road Safety officers; basic training for officers needed; poor level of coordination, reporting and data flow between TMPD and SAPS • Effective and efficient law enforcement is hindered by the current inadequately implemented legal system for prosecuting offenders (AARTO) • Lack of coordination between various role players

Source: Adapted from City of Tshwane (2015: 14-8)

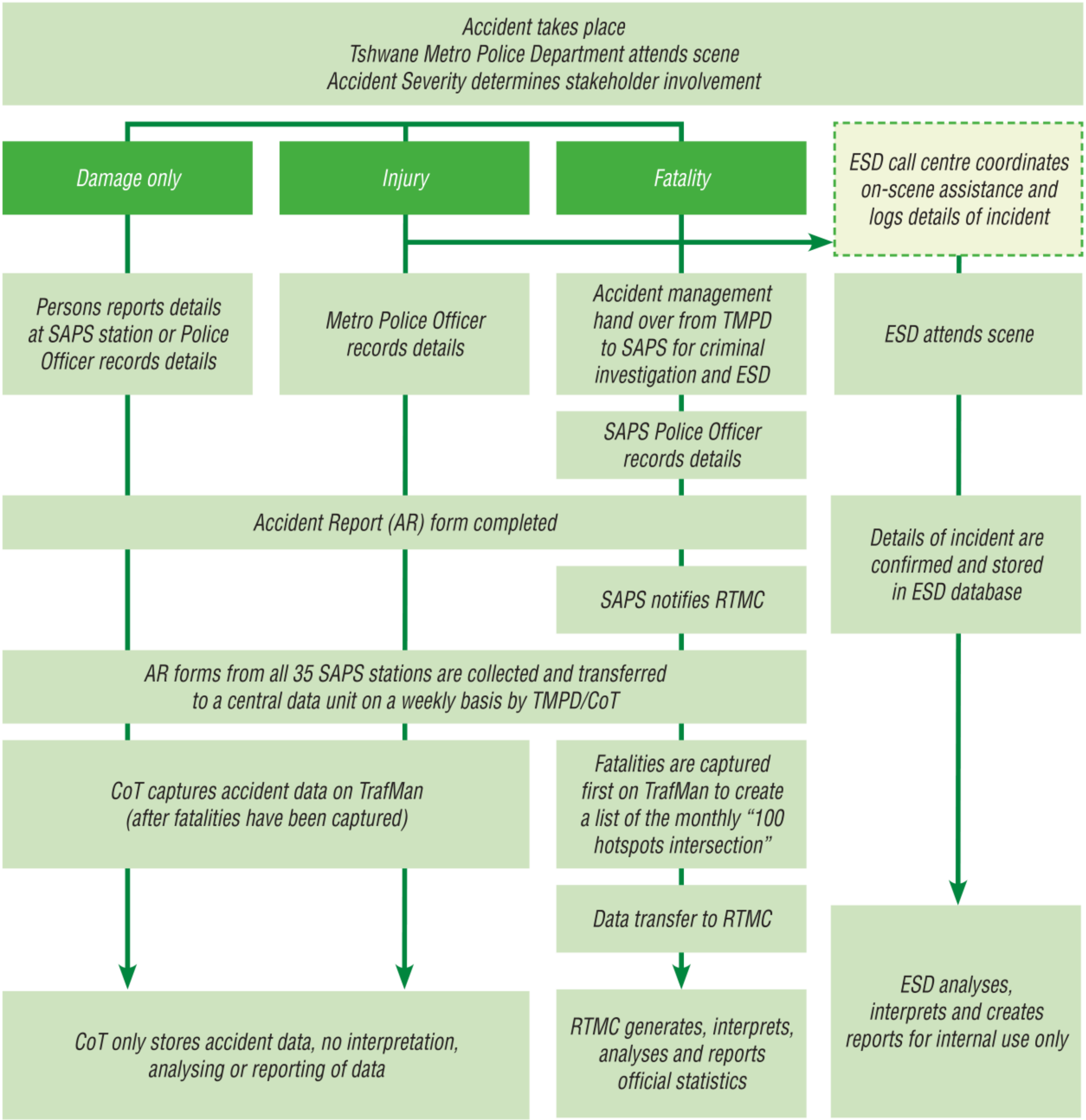

Figure 2.3: Data collection process including on-scene management and stakeholder involvement
Source: City of Tshwane (2015: 14-11)

The CTMM possesses a well-developed data collection and analysis process as depicted in Figure 2.3, however the process exhibits shortcomings typical of accident databases. Mitigation measures for the data collection process are continually required to address issues such as under reporting, dark figures as well as data not normalised in terms of the volume of vehicles per site and distance travelled. This inadequate interpretation of accident statistics, especially with regards to the monthly top 100 intersection "hotspots", may lead to scarce funding and resources being incorrectly prioritised. In order to avoid interpretation errors, intersections with the highest number of accidents cannot be interpreted as being equivalent to intersections with the largest number of accidents in terms of the Rate per Million of Entering Vehicles (RMEVs).

2.3 International standards and best practices in road safety

The Safe Systems approach

The Safe Systems approach is internationally accepted as best practice in road safety strategy and requires a more forgiving approach to accidents and acknowledges that while human error is the largest contributory cause of crashes, a greater focus and "cushioning" is required from all other system aspects, in order to reduce and mitigate any potential injury or loss during a crash. The principles of the Safe System approach are summarised as follows (Department of Transport 2016: 13):

- People make mistakes, and the road transport system must absorb these mistakes to prevent death or serious injury as a result of road user error.
- The system has to accommodate the physical limits to human frailty and the amount of force our bodies can take before we are injured.
- To achieve a 'forgiving' road system that ensures that the forces in collisions do not exceed the limits of human tolerance. System designers need to consider the limits of the human body in designing and maintaining roads, vehicles and speeds.

The International Transport Forum (2018: 56) state that the plateauing of past downward trends in crash reduction of well-performing countries indicates that tried and tested approaches to reduce traffic fatalities may be reaching the limits of their effectiveness. The Safe System approach promises a more integrated, holistic method capable of additional improvements to road safety when combined with traditional methods.

Road Traffic Safety (RTS) Management System – ISO 39001

The International Organization for Standardization presents ISO 39001 as a tool to assist organisations to reduce or eliminate the risk of death and injury related to road traffic crashes, in order to develop a more cost-effective use of the road traffic system (International Organization for Standardization 2012: 7). This approach is supported by the CTMM Roads and Transport Department, which in partnership with the South African Bureau of Standards (SABS), is currently in the process of pursuing ISO 9001 Quality Management System certification which shares similar principles to ISO 39001. The interconnected principles provided by ISO 9001 will provide an excellent foundation from which to further develop an RTS management system with the eventual goal of obtaining ISO 39001 certification.

ISO 39001 is intended for use by various public and private organisations regarding the following (Crackel and Small 2010: 3):

- The transportation of goods and people including the taxi and freight industries.
- The operation of facilities that generate demand for transport, such as shopping centres and schools.
- Personnel working within the road transport industry.
- Road authorities responsible for the design, building, operation and maintenance of roads and road environments.
- Manufacturers involved in the design and production of cars, trucks and other road vehicles.
- The provision of emergency medical assistance to crash victims.

The organisational benefits for implementing road safety management systems include (International Organization for Standardization 2017: 3):

- Alignment with national and global efforts to prevent death and serious injury in road crashes.
- Mission and vision of organisations to address an issue of significant public concern.
- Management of an organisation’s primary occupational safety risks.
- Reduce organisational road crash costs and working days lost to injury.

- Enable the efficient use of available resources to mitigate road safety risks.
- Organisational advancement with improvement of public profile and increase in business.
- Acquire a competitive edge in tendering processes.
- Lower insurance premiums and repair costs.

Road Safety Management Systems are further described by Bliss and Breen (2013: 33) as comprising three interconnected elements, namely: institutional management functions, interventions, and results. As depicted in Figure 2.4 below, the system highlights an integrated and accountable response with special emphasis placed on the lead authorities' responsibilities in terms of seven institutional management functions. The World Report on Road Traffic Injury Prevention, published by the World Bank, provides six sequenced recommendations towards developing a road safety system (Bliss and Breen (2013: 11):

1. Identify a lead agency in government to guide the national road safety effort.
2. Assess the problem, policies and institutional settings relating to road traffic injury and the capacity for road traffic injury prevention in each country.
3. Prepare a national road safety strategy and plan of action.
4. Allocate financial and human resources to address the problem.
5. Implement specific actions to prevent road traffic crashes, minimise injuries and their consequences and evaluate the impact of these actions.
6. Support the development of national capacity and international cooperation.

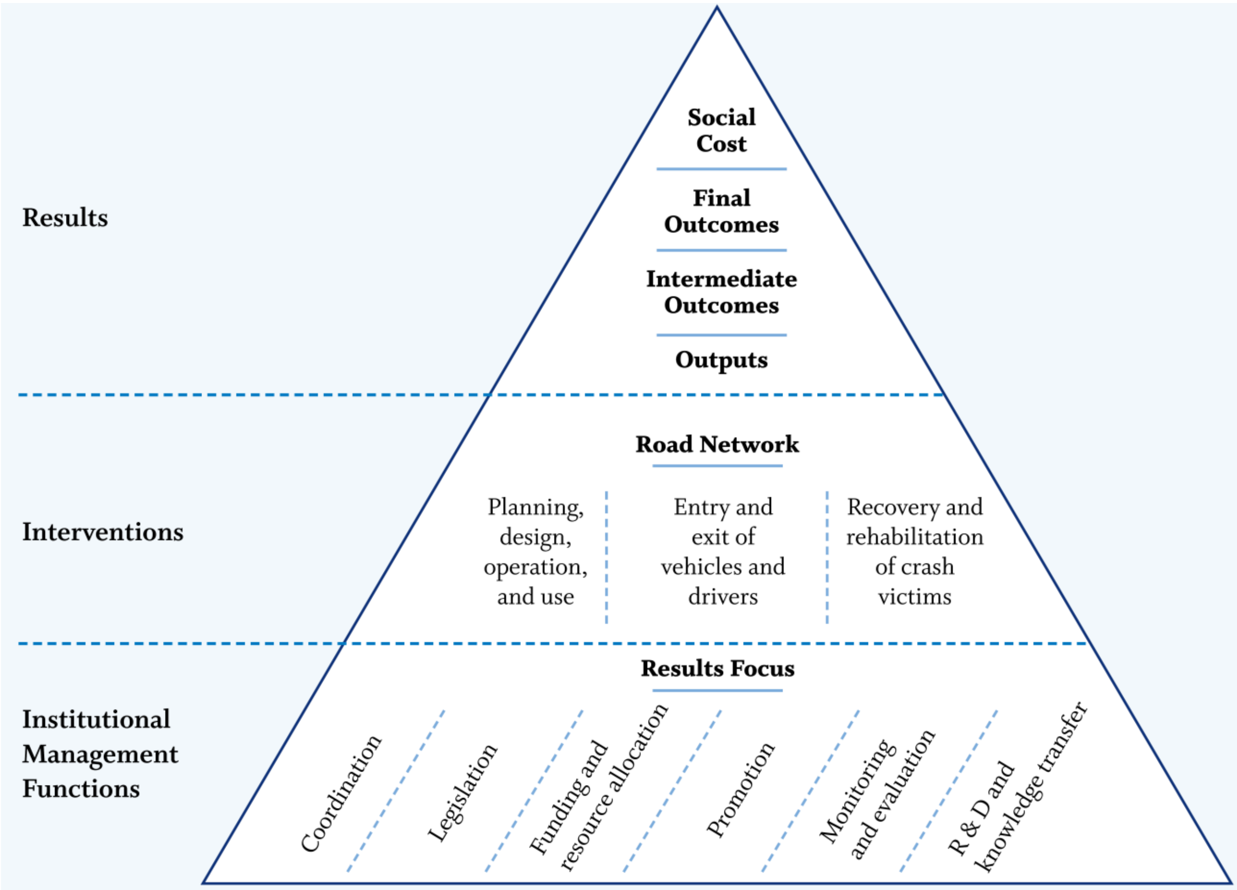

Figure 2.4: Generic road safety management system
Source: Bliss and Breen (2013: 34)

The road safety management system described as per Figure 2.4 above allows for a universal application to both developed and developing countries irrespective of its institutional performance, structure or culture. It describes the production of road safety and acknowledges that safety is produced just like any other goods and services. The production process commences with institutional management functions which produce interventions that in turn produce results. Traditional road safety focuses on risk exposure and interventions alone, and the use of management systems accounts for the frequently neglected issues of institutional ownership and accountability of results.

2.4 Road safety management process

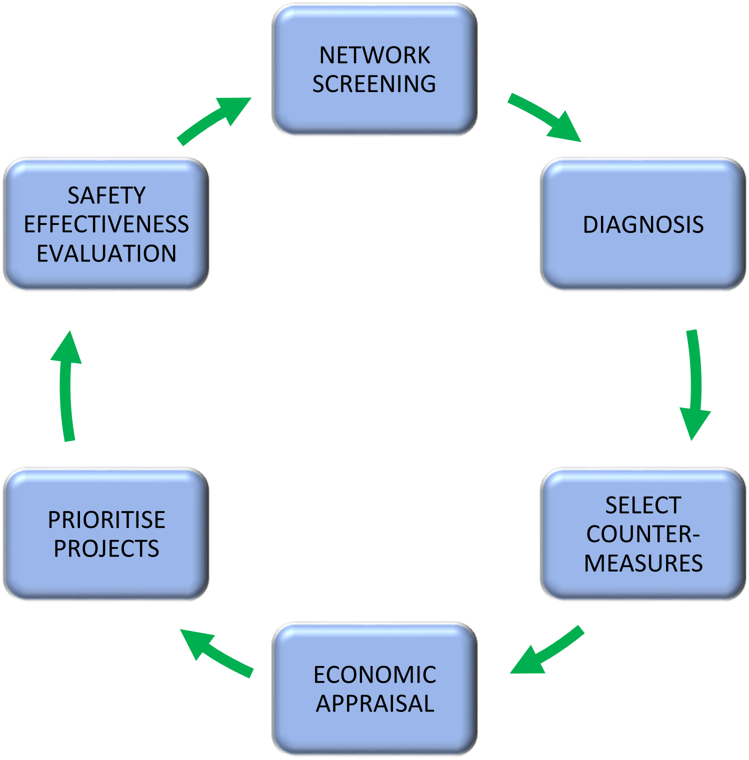

Figure 2.5: The roadway safety management process
Source: Adapted from Kolody et al. (2014)

The roadway safety management process describes the relationships for safety performance based on exposure and roadway conditions. The process as per Figure 2.5 above, can be summarised as follows (Kolody et al. 2014: 2-2):

➢ **Network screening**

In this step the transportation network is reviewed to prioritise sites based on the potential for reducing average crash frequency and/or crash severity. The screening process comprises five steps: establish the focus of network screening, identify the network and reference population, select the performance measures, select screening method, and evaluate the results. Typical performance measures include Crash Rates per 100 Million Vehicle Kilometres (RMVKs) for road segments or Crash Rates per Million of Entering Vehicles (RMEVs) for intersections.

- **Diagnosis**

The purpose of this step is to identify the contributing factors to crashes such as: crash patterns, crash types, weather, road layout, and vehicle or human factors that may be relevant for the sites under investigation. Diagnosis is undertaken by reviewing existing crash data, assessing supporting documentation about the site conditions, and conducting an onsite field review. The appropriate safety counter measures can thereafter be selected to be used in mitigation of any identified trends or crash patterns.

- **Selection of countermeasures**

Appropriate safety countermeasures can be selected after contributing factors have been identified. Multiple factors may be contributing to each identified crash pattern or type of crash. Crash sites are unique, therefore requiring both engineering judgement and statistical assessment in order to identify the greatest contributing factors and countermeasures. Examples of countermeasures include guardrails, traffic signs, pedestrian bridges and median islands.

- **Economic appraisal**

The economic appraisal of a safety countermeasure or combination of countermeasures is to determine the countermeasure cost and determine which project or alternative is the most cost-effective. Also included in the economic assessment is the expected improvement in the average fatal, injury, and property damage crash frequency which is converted into a monetary value. Financial tools such as Net Present Value (NPV) or Benefit-Cost Ratio (BCR) can be used to rank the economic viability of projects.

- **Prioritisation of projects**

The prioritisation of projects considers numerous factors with a process known as multi-objective resource allocation, which is used to quantify the effect of multiple factors including: safety in terms of the reduction in crashes, traffic operations in terms of the reduction of delay or improvement in Level of Service (LOS), and environmental benefits in terms of the emissions reduced.

- **Safety effectiveness evaluation**

Safety effectiveness evaluation is the assessment of how crash frequency or severity has improved or changed because of a specific treatment or safety countermeasure and how well funds have been invested in reducing crashes. Safety effectiveness evaluations may use various types of performance measures, such as a percentage reduction in crashes, a shift in the proportion of crashes by collision type or severity level, or a comparison of the crash reduction benefits achieved in relation to the cost of a project. Although the roadway safety management process and the North American developed HSM may not be generally applicable for use in the current South African context (Roodt 2012: 502), an understanding of the manual's principles and processes would be of benefit to South African road safety practitioners.

2.5 Simplified methodology to prioritise road safety projects

The cost and time required to develop fully fledged crash analysis systems would likely create extended periods where road authorities are without the required tools for the programming of road safety projects. The eThekwini municipality provides a simplified methodology for the ranking of road safety interventions which is not heavily dependent on large data and time requirements and where data is limited to information obtained from desktop studies, accident counts, traffic counts, site visits, and consultation with affected communities or ward councillors. The following are the three parameters and the ranking system proposed by the eThekwini Municipality with an amendment made by the writer to include only actual accident rates instead of estimated accident rates (eThekwini Municipality 2012: 51):

1. **Relative community rating** – This parameter, although often not objective and subject to bias, is an important aspect to include, especially in the local government environment where valuable information regarding the safety issue can be obtained. This parameter is rated on a scale of 1 to 10, where no comment received from the public is rated as 1 and if there are a large number of people complaining about a specific problem, it may be rated as 10.
2. **Crash Rate** – The number of accidents is normalised with traffic volumes by means of crash rates. Crash rates are determined on the basis of exposure

data, such as traffic volumes and the length of road section being considered. Commonly used rates are, Crash Rate per Million of Entering Vehicles (RMEVs) for intersections and Crash Rate per 100 Million Vehicle Kilometres (RMVK) for road segments (Garber and Hoel 2015: 190).

3. **Cost of Upgrade** – The cost of the proposed upgrade required to address the safety issue is estimated and then ranked. A subjective scale based on engineering judgement may be used, where for example projects of less than R50 000 will score 1 and projects of more than R3 million will score 10.

As per the example shown in Table 2.2 below the ranking is calculated based on the following equation (eThekwini Municipality 2012: 53):

$$Ranking\ Score = \frac{Community\ Rating + Crash\ Rate}{Cost\ of\ Upgrade}$$

Table 2.2: Simplified methodology to prioritise road safety projects

CRITERIA	PROJECT		
LOCATION	**A**	**B**	**C**
Description of Problem	An intersection close to a school where there are several learners and parents complaining. There are, however, few accidents and the traffic volumes are 3 000 vehicles per day. The solution is a raised pedestrian crossing at a cost of R40 000.	An intersection has high right turn volumes (greater than 5 000 vehicles per day) and requires a right turn lane, which will cost R3 million to construct. There is one accident per month, mostly rear end collisions. A few members of the public have complained.	A median island, costing R500 000 is required to stop vehicles doing illegal U-turns on a major arterial road. Approximately three accidents occur per year. Some members of the public have complained.
Community Rating	10	1	5
Accident Rating	4	5	3
Cost Rating	2	9	5
Ranking Score	**7**	**0,67**	**1,6**

Source: eThekwini Municipality (2012: 53)

2.6 Road safety audit and appraisal

International origins of Road Safety Audits

The starting point of RSAs was introduced in the form of In-service Road Safety Reviews (ISRSRs) in Europe in the early 1980s due to observations and concerns from road authorities that many newly completed road projects often experienced high crash and injury rates. In 1991 ISRSRs became mandatory for all national roads and motorways in the United Kingdom. In the early 1990s ISRSRs were also used in Australia and New Zealand and towards the late 1990s ISRSRs and RSAs were employed in Australia, New Zealand, Canada, the United States, Denmark, Netherlands, Singapore, and South Africa (Road Traffic Management Corporation 2018: 5).

South African Road Safety Audit Manual (2012)

The South African Road Safety Audit Manual (Road Traffic Management Corporation, 2012: 17) provides the following key definitions of terminology applicable to this research:

A **Road Safety Engineering Assessment** is described as, *"a screening process to establish the road safety status of sections of an existing road network."*

A **Road Safety Audit** is defined as *"a formal examination process of a new or upgrading project where interaction with road users takes place, in which an independent and qualified team identifies potential road safety problems and suggests measures to mitigate those problems."*

A **Road Safety Appraisal** is defined as *"a systematic examination process of an existing road location, in which an independent and qualified team reviews onsite conditions and available historical evidence to identify existing or potential road safety problems and suggest measures to mitigate those problems."*

The RTMC was established in terms of Section 3 of the Road Traffic Management Corporation Act, No. 20 of 1999, and serves as custodian of the SARSAM (Road

Traffic Management Corporation 2012). Although RSAs are currently not mandatory on all South African road projects, it remains the responsibility of road authorities to consult with best practice guideline documents in order to limit exposure to any legal risks (Road Traffic Management Corporation 2012: 2). The SARSAM (2012) recognises the “Safe System” approach as global best practice, a system which is able to accommodate human error and takes into consideration the vulnerability of the human body. It recognises that even the most law-abiding and careful humans will make errors. The challenge under a Safe System approach is to manage the interaction between vehicles, travel speeds and roads with the primary emphasis on reducing fatalities and serious injuries, with the secondary priority of reducing the number of overall crashes. The Safe System philosophy requires a paradigm shift, to not solely blame road users for their mistakes in the event of crashes (Road Traffic Management Corporation 2018: 12).

The benefits of RSAs as a crash prevention tool include (Road Traffic Management Corporation 2012: 20):

- A reduction in the likelihood of crashes on the road network.
- A reduction in the severity of crashes on the road network.
- An increased awareness of safe design practices among engineers and designers.
- A reduction in the need to modify projects after they are implemented.
- A reduction in the life-cycle cost of a road.
- A more uniform road environment that is more easily understood by road users.
- A better understanding and documentation of road safety engineering.
- Eventual safety improvements to standards and procedures.
- More explicit consideration of the safety needs of vulnerable road users.

2.7 Traffic impact assessment and road safety

Traffic Impact Assessments (TIAs) and Site Traffic Assessments (STAs) in South Africa are governed by the Technical Methods for Highways (TMH) manuals TMH 16: Volume 1: South African Traffic Impact and Site Traffic Assessment Manual (Committee of Transport Officials 2012a) and TMH 16: Volume 2: South African Traffic

Impact and Site Traffic Assessment Standards and Requirements Manual (Committee of Transport Officials 2012b). The purpose of the TMH 16 manuals are to establish uniform and consistent requirements and standards for Traffic Impact Assessments and Site Traffic Assessments in South Africa. The primary aim is to ensure sustainable development by means of the provision of an efficient transport system, the effective management of land development to reduce the need to travel, and promoting more sustainable forms of transport such as public transport, walking and cycling (Committee of Transport Officials 2010a: 1). The TMH 16 manuals, however, do not adequately address road safety issues in the form of an explicit assessment procedure. In addition, the sole reference to road safety assessments or audits is applicable for heavy goods vehicles only (Committee of Transport Officials 2012b: 98).

Standards for Australian Traffic Impact Assessments provide a more comprehensive road safety assessment procedure, which describes an assessment as necessary to determine if there is likely to be any significant change to the level of road safety risk on the public road network with the proposed development. The three-stage procedure requires the comparison of safety risks, firstly without the development or existing conditions, secondly with the proposed development and finally with the proposed development including mitigating measures (Department of Transport and Main Roads 2017: 33).

Table 2.3: Risk scoring matrix

		Potential Consequence				
		Property only (1)	**Minor injury (2)**	**Medical Care (3)**	**Hospital Care (4)**	**Fatality (5)**
Potential Likelihood	**Certain (5)**	M	M	H	H	H
	Likely (4)	M	M	M	H	H
	Moderate (3)	L	M	M	M	H
	Unlikely (2)	L	L	M	M	M
	Rare (1)	L	L	L	M	M

Source: Department of Transport and Main Roads (2017: 36)

The Risk Scoring Matrix as per Table 2.3 above requires scoring to be undertaken and tabulated for all risk items in the impact assessment area. Qualitative scoring is indicated as L for low risk, M for medium risk and H for high risk. The Risk Scoring Matrix assesses risk in terms of:

- Likelihood: the probability or frequency of an event or situation occurring.
- Consequence: the effect, result or outcome of something occurring.

Table 2.4: Type of assessment based on risk rating

Development Type	Road Environment Safety Rating		
	Low	Medium	High
Major Development	road safety assessment	road safety audit	road safety audit
Planning Act Dev.	road safety assessment	road safety assessment	road safety audit

Source: Department of Transport and Main Roads (2017: 37)

As per Table 2.4 above the Australian standards further require that where a road safety assessment or audit has been identified as being required, concept design plans of the proposed project will be required as a basis for the assessment which is to be conducted by a registered and independent road safety auditor (Department of Transport and Main Roads 2017: 37-38). It is suggested that South African standards should incorporate Australian guidelines and allow for the incorporation of road safety assessment and audit procedures as a policy requirement for TIAs submitted for approval to the CTMM. This would allow for road safety issues to be resolved at the earlier conceptual design stage at the cost of the developer rather than permitting development projects to be implemented with unsatisfactory risks that may only become apparent after the project is handed over to the CTMM or other relevant road authorities and the road is opened to public road users. According to the Road Traffic Management Corporation (2018: 29), the SARSAM (2012) generally corresponds to international guidelines, however further work is required in mandating the SARSAM for widespread use in the South African roads industry, which would include re-packaging the SARSAM into the TMH and TRH series of standards. The inclusion into the TRH series of documents should also address the need for screening at an existing road network level, including specialist reviews for more in-depth assessment.

2.8 Design standards – nominal safety versus substantive safety

South African road construction and upgrade projects typically address safety through the application of design standards, specifications and guidelines which are in turn based on the relevant road authorities' policies and design manuals. Geometric design requires the application of design standards with the end goal of achieving transportation performance which encompasses aspects such as mobility, accessibility, safety, and life cycle costs. It should be considered, however, that these documents may not explicitly address road safety issues. Design philosophy should change from a "one-dimensional" standards-based approach to a performance-based approach. The traditional approach to design is based on the assumption that minimum design criteria are adequate to produce an acceptable level of safety where roads are characterised in "absolutes" that is, as being either unsafe or acceptably safe, and that the application of minimum design criteria produces a safe roadway. This "nominal safety" approach focuses on minimum standards where designers are dissuaded from providing more than the minimum values or dimensions as doing so is assumed to increase the construction cost with no added value. The nominal safety approach therefore does not provide incentives to readily consider design alternatives that may allow for improvements in safety performance (Neuman, Coakley and Harwood 2017: 49).

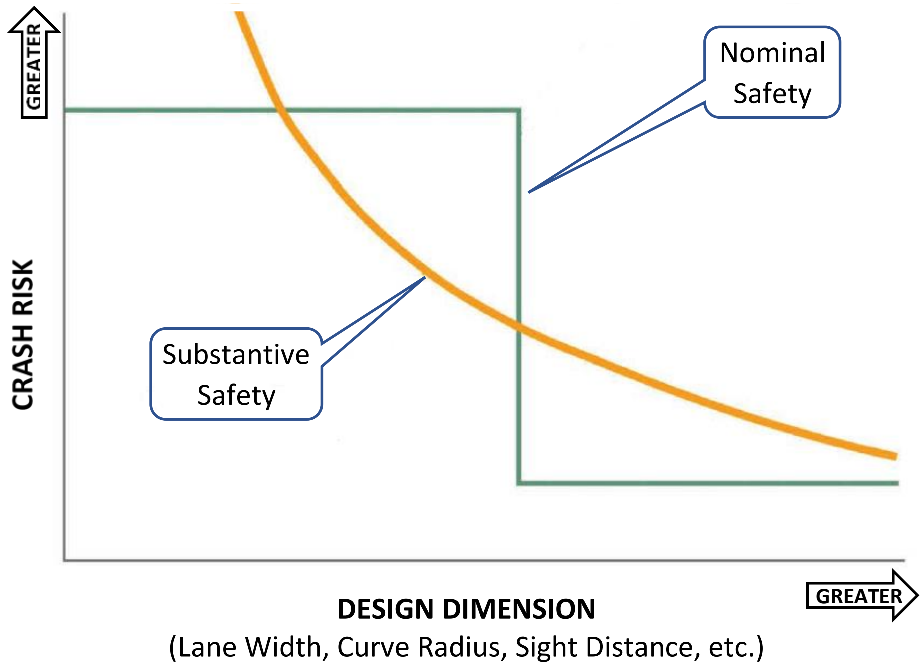

Figure 2.6: Nominal safety versus substantive safety
Source: Neuman, Coakley and Harwood (2017: 50)

Road safety, as described by the risk of the expected crash frequency and severity, is not an absolute, as depicted by the application of nominal standards and the green line shown in Figure 2.6 above. Minimum design standards and geometric criteria are established with the knowledge available at the time and typically based on relationships or models unrelated to road safety performance. Substantive safety as depicted by the orange line in Figure 2.6 is described as a continuum where a range of values and associated benefits and risks may be analysed in order to achieve improved roadway safety performance. The general relationship of the orange line is intuitively adaptable to other roadway elements and dimensions, including lane and shoulder widths, radius of curve, and grade variations. In terms of limiting professional liability and legal risk, an important aspect of a civil engineer's role is to ensure that the road design process does not solely rely on criteria or dimensions, but should exercise engineering judgement and be accountable for such judgements. The road design process is sufficiently complex such that a simple, formulaic, or rote design process is not possible. However, on the other end of the spectrum, a geometric design process that routinely incorporates exceptions to what are supposed to be appropriate best practices, dimensions, or standards, is considered to be suboptimal. The design goal should not only be the application of minimum criteria, but rather a combination of criteria that takes advantage of new research and technological innovations such as new road safety countermeasures and autonomous vehicles. This optimisation of safety performance allows for projects to be completed taking into account the capital and life cycle costs as well as the project context in terms of the local, regional and national framework (Neuman, Coakley and Harwood 2017: 49-60).

2.9 The causes of crashes

The causes of crashes, including fatal crashes, are traditionally ascribed to human factors such as driver behaviour and error as being the overwhelmingly largest contributor to crashes. While many transportation engineers focus on minimum standards and the 12.3 % attributed to "Roads and Environment" as illustrated in Figure 2.7 below, greater reductions in fatalities may be achieved by directing scarce resources and funds towards a "safe systems" approach that allows for adequate cushioning of minimum standards in order to reduce the 73.6 % “human factors” influence on fatalities.

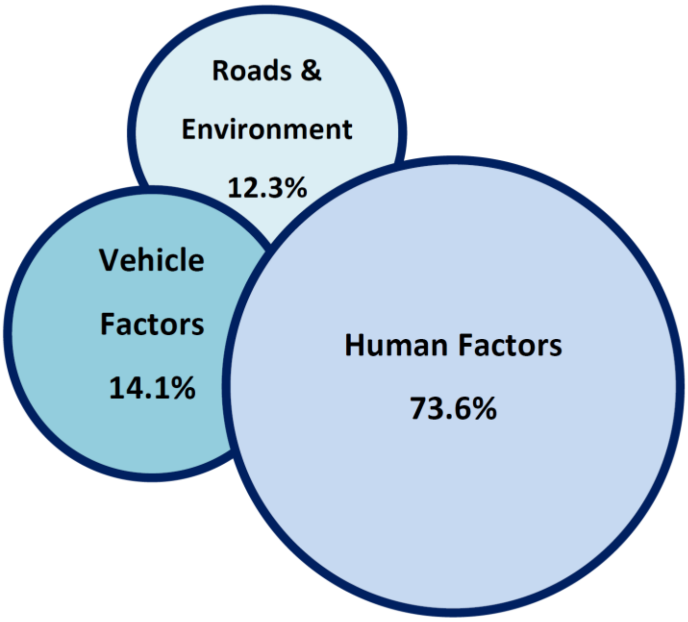

Figure 2.7: Causes of fatal crashes – South Africa
Source: Department of Transport (2016: 27)

The second pillar of the UNDA for Road Safety 2011-2020 is titled “Safer Roads and Mobility” which focuses on road design and the environment. This strategy requires various approaches including the development of forgiving road designs and the mitigation of risks within the road network by means of routine road safety assessments or audits. Figure 2.8 below from the South African National Road Safety Strategy 2016-2030 (Department of Transport 2016) indicates sharp bends as the leading contributor to fatal crashes under the category of road and environment factors. Physical factors such as blind rises, blind corners and sharp bends tend to enable and amplify human error and needs to be diminished by means of appropriate “cushioning” amendments to road design. In addition, road environment conditions such as poor road surface conditions contribute to 8.3 % of total accidents, which can be attributed to South Africa’s road maintenance backlog of 37 % which requires a substantial sum of R197 billion to remedy (Department of Transport 2016: 31).

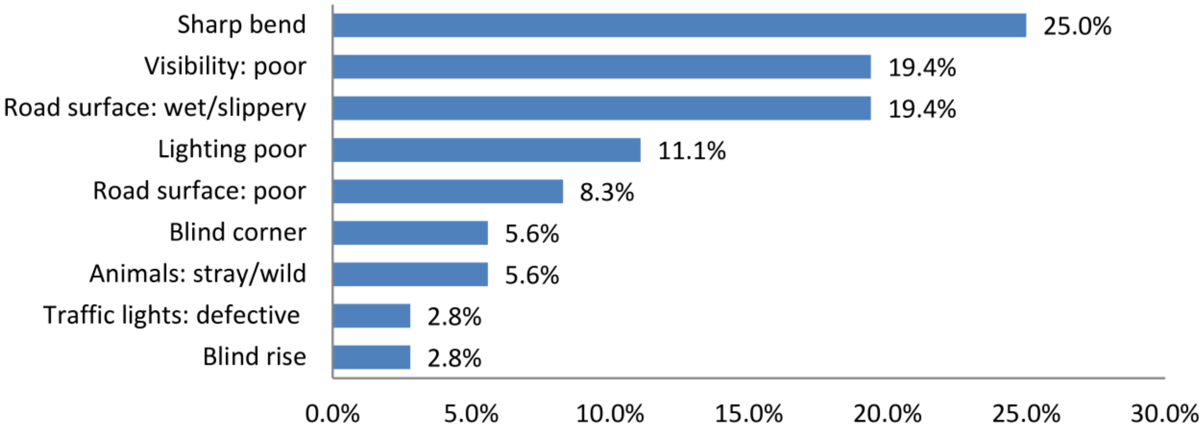

Figure 2.8: Road and environmental factors resulting in fatal crashes
Source: Department of Transport (2016: 31)

The safer vehicle strategy is supported by improved vehicle safety technologies for both passive and active safety such as autonomous vehicle technology and strengthened global standards in vehicle safety. In the South African context, data indicates that burst and smooth tyres contribute collectively to 80 % of vehicle factors resulting in crashes. Other vehicle factors resulting in crashes include faulty brakes (11.4 %), overloading passengers (2.9 %), bicycles lack of rear reflectors (2.9 %), and faulty steering (2.9 %).

The fourth pillar of the UNDA for Road Safety 2011-2020, is titled “Safer Road Users” and focuses on road user programmes, public education campaigns and enforcement of laws and standards in order to improve road user behaviour. Although jaywalking as shown in Figure 2.9 below is identified as the highest human factor contributing to crashes at 42.6 %, it should be noted that the behaviour of pedestrians is often related to the lack of safer infrastructure such as pedestrian bridges and paved walkways.

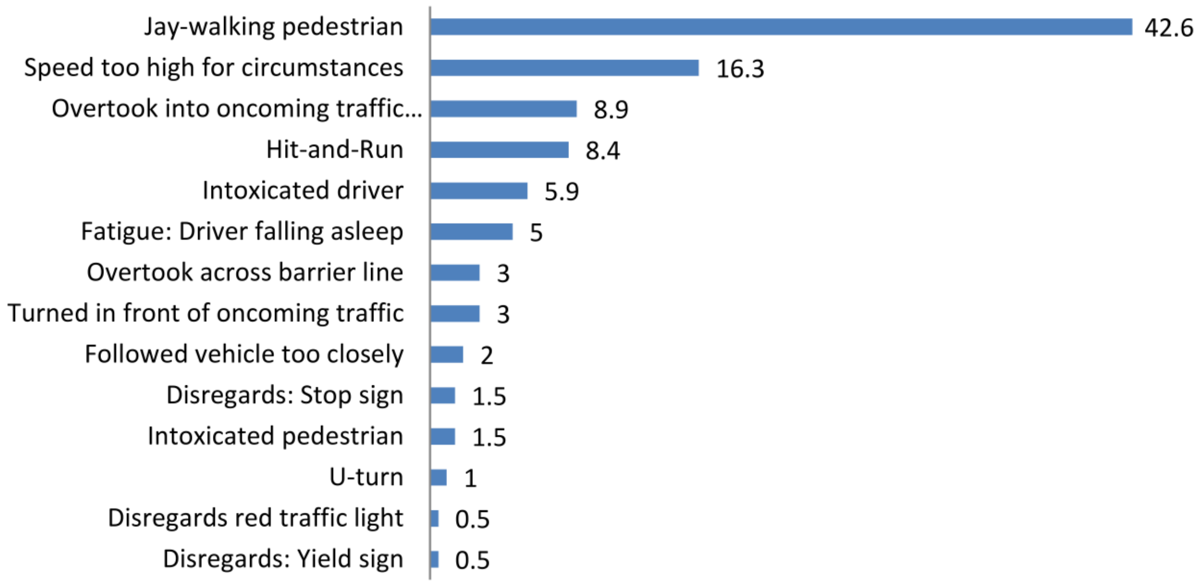

Figure 2.9: Human factors resulting in fatal crashes
Source: Department of Transport (2016: 34)

The majority of road user behavioural issues including speeding, overtaking into oncoming traffic, intoxicated road users and fatigue can be addressed by effective law enforcement and education campaigns. A contributing factor to many of the behavioural issues include inattentive and distracted driving where drivers engage in secondary activities unrelated to driving, which include the use of cell phones, eating, smoking, grooming and passenger distractions (Department of Transport 2016: 34).

Garber and Hoel (2015: 151) state that while the causes of crashes are typically complex, these causes can be considered in four separate categories:

- Human factors – actions by the driver, operator or pedestrians.
- Vehicle factors – the mechanical condition of a vehicle.
- Roadway factors – the condition, quality and geometric characteristics of the roadway.
- Environment factors – the climatic and physical environment.

These categories, while similar to the UNDA for Road Safety 2011-2020, provide new perspectives to the familiar categories, perspectives which are more suited to developing countries rather than developed countries.

Human factors

The human errors leading to crashes may involve the complex interaction of drivers' psychological and physiological conditions as well as vehicle, roadway and environmental conditions. Driver errors contributing to crashes include driving at an inappropriate speed for existing conditions, driver inattentiveness or distraction, roadway distraction, driver weariness, information overload, and driver expectancy.

The roadway design considerations to reduce information overload include (Garber and Hoel 2015: 151):

- Consistency in display of traffic information, such as specific colours and shapes assigned to specific types of road signs and markings.
- Providing information in an orderly manner and not too much information at the same time.
- Providing clues to help drivers rank the importance of different information, such as increasing standard sizes of traffic signs to increase its importance as required in specific conditions.

The improvement of consistency and driver expectancy also reduces the negative effect of the driver's limitation in processing information. For example, the location of a freeway exit on the right-hand side of the roadway instead of the typical left hand side of the roadway would cause confusion and may result in unnecessary weaving manoeuvres. Transportation engineers and designers are also required to specifically prioritise schools and learners, as pedestrians are the most vulnerable road user group and account for approximately 40 % of all road fatalities (Department of Transport 2016: 31).

Vehicle Factors

Vehicle conditions contributing to crashes can include failure of the electrical systems, worn tyres, faulty brakes and overloading of passengers. Conversely new vehicle technologies may also reduce the likelihood and severity of crashes and include measures such as seat belt reminders, antilock braking systems, speed limiters and varying levels of autonomous vehicle systems. The most promising technology supportive of road safety are self-driving autonomous vehicles, however new vehicles are becoming much more durable, which reduces fleet turnover. As a result, new vehicle technologies such as autonomous vehicle systems will probably require three to five decades to penetrate 90 % of vehicle fleets. It will probably be the late 2030s or 2040s before autonomous vehicles become affordable to middle-income households, and even later before they are affordable to lower-income motorists (Litman 2019: 30).

Roadway and Environment Factors

Roadway condition and quality factors include the pavement, shoulders, intersections, curvatures and the traffic control system. Road designs are required to provide adequate stopping sight distance at the design speed, in order to allow motorists enough time to take remedial action to avoid a crash (Garber and Hoel 2015: 152). The "positive guidance approach" takes into account human limitations in information processing as well as human dependence on expectations to make up for these limitations.

Weather can also contribute to crashes. For example, rainy weather reduces the road pavement's ability to provide friction and can increase stopping distances and cause vehicles to hydroplane. Factors such as the poor level of visibility and lighting as experienced during fog, late-night or early-morning periods, increase the probability of crashes occurring; where 40 % of intersection fatalities occur during the late night or early morning hours (Garber and Hoel 2015: 153).

2.10 The relationship between road safety and traffic congestion

A fundamental objective of traffic analysis for roadways is to measure a roadway's performance in relation to specified traffic volumes. This comparative analysis of various road segments is of importance as it provides a method to prioritise and allocate limited funds to required projects (Mannering and Washburn 2013: 171). There are various ways of measuring congestion which may include the use of different parameters such as volume, density, occupancy, queue length, travel time, delay, speed, volume to capacity ratio (v/c) and Level of Service (LOS). Current practice defines six levels of service ranging from A to F, with LOS A describing free flow conditions whereas LOS F indicates congested flow. The volume to capacity ratio is defined as the volume divided by capacity with a v/c ratio of 0.8 or 0.85 recognised as the commonly accepted threshold for congested flow conditions (Marchesini and Weijermars 2010: 12).

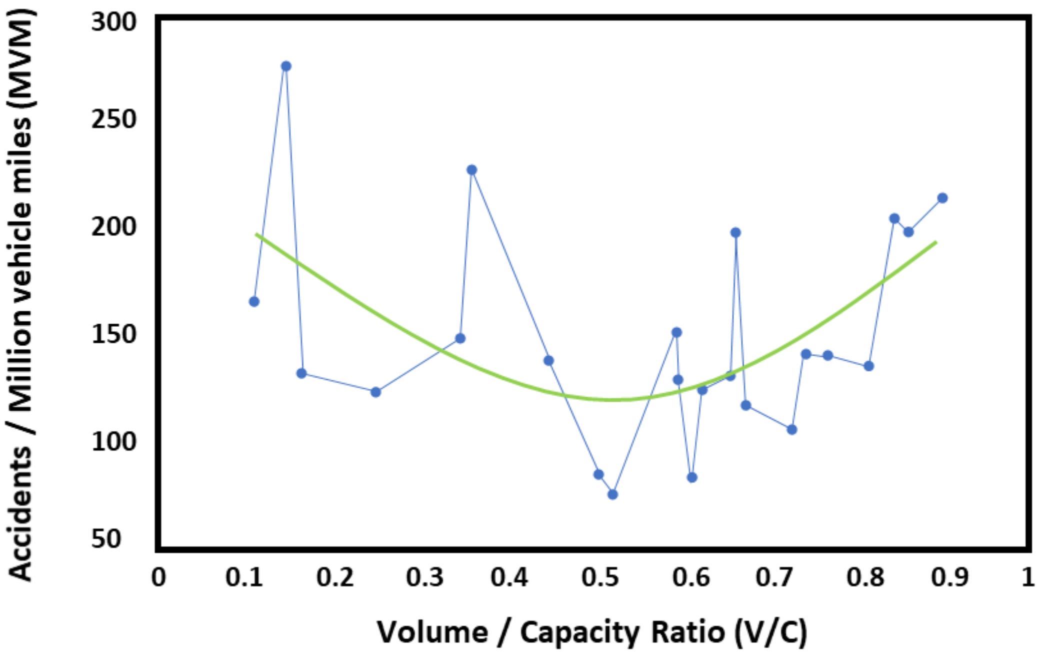

Figure 2.10: Accident rate versus v/c ratio for weekday only
Source: Adapted from Zhou and Sisiopiku (1997: 50)

The U-shaped graph in Figure 2.10 above is more representative of accident exposure as it includes both road geometric and operational characteristics. The function is further described by time periods with low v/c characteristics (for example at night-time) displaying high accident rates. As the v/c rate increases the accident rate decreases, reaching a minimum at approximately 50 % to 60 % v/c capacity and increases again as the v/c approaches congested traffic flow conditions. However, the study also found that for injury and fatal crashes an increasing v/c ratio results in decreasing accident severity rates, which could be explained by typically lower average speeds during v/c levels approaching capacity or congestion. Conversely, single-vehicle accident rates indicate a decreasing trend with increasing v/c ratios. In addition, factors other than capacity issues such as alcohol, fatigue and lighting conditions more often occur during off-peak traffic periods. It appears to the writer that the 50 % to 60 % v/c ratio describes a more uniform, routine and predictable traffic flow often experienced during working commutes which results in improved driver expectancy and so are the safest traffic periods.

2.11 Crash risk and intersection conflict points

Intersection conflicts occur when traffic moving in different directions affect or interfere with each other. The number of crashes at an intersection is typically associated with the number of intersection conflict points and includes the magnitude of conflicting flows at each conflict point. A conflict point is further described as a location where the paths of motor vehicles or NMT modes (such as a bicycle or pedestrian) queue, diverge, merge, or cross each other. Although traffic control devices are able to reduce many conflicts, it is unable to prevent all conflicts due to illegal traffic violations, such as the failure to yield or stop for pedestrians at the required traffic signs.

A conflict analysis process typically considers the following factors (Federal Highway Administration [FHWA] 2000: 104):

- Identification of all conflict points.
- Exposure, measured as the product of conflicting stream volumes at a given conflict point.
- Severity, based on the speed differential of the conflicting streams (speed and angle).
- Vulnerability, based on the ability of the differing transport modes of each conflicting stream to survive a crash.

The four basic types of manoeuvres that result in conflict at intersections are shown in Figure 2.11 below in order of typically increasing severity (Department of Transport and Main Roads 2006: 13-15):

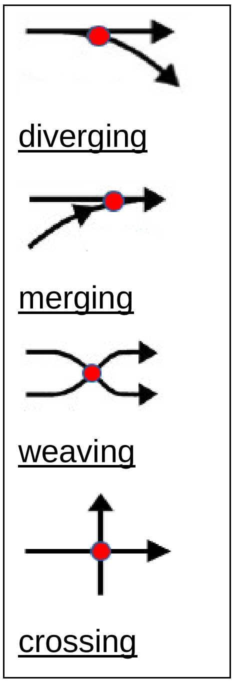

Figure 2.11: Typical intersection conflict manoeuvres
Source: Department of Transport and Main Roads (2006: 13-15)

Vehicle-pedestrian conflicts are common to most intersections on the urban road network. Signalised intersections are able to reduce the probability of pedestrian-vehicle conflicts through the use of signal phasing that allows only a few movements at any given time. A pedestrian crossing at a typical signalised intersection faces four potential vehicular conflicts, each coming from a different direction:

- Crossing movements on red (typically high-speed, illegal).
- Left turns on green (legal).
- Right turns on green (legal for right turn phasing).
- Left and right turns on red (illegal).

The illegal movements in regards to exposure are allocated a lower weight than legal conflicts, however in terms of severity they may be allocated an offsetting higher weight (FHWA 2000: 108).

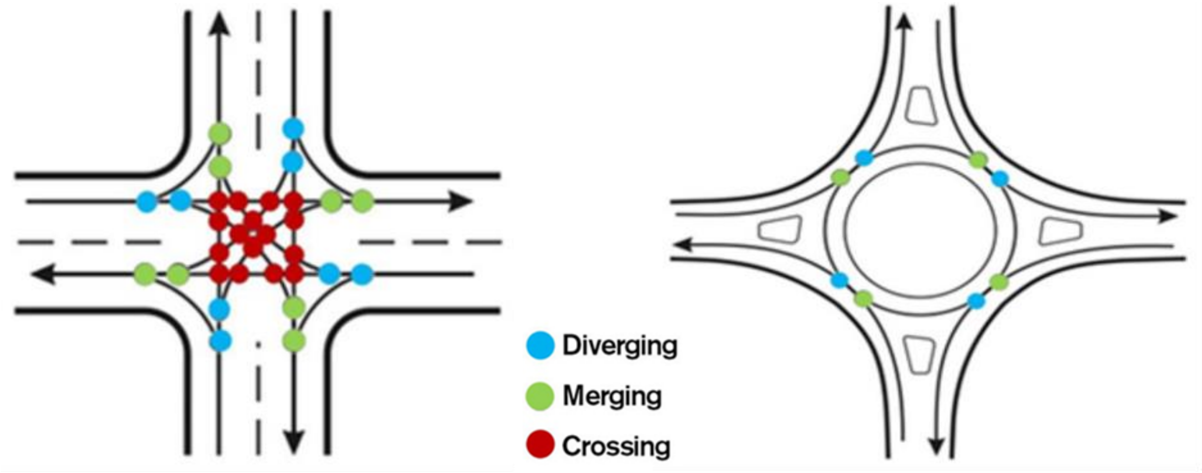

Figure 2.12: Typical intersection conflict points
Source: Arizona State University (2019)

Figure 2.12 provides a comparison between a typical four-legged, traffic signal-controlled intersection and a single lane roundabout noting that the frequency of crashes is often related to the number of conflict points at an intersection including the extent and distribution of traffic volumes. A conflict point is a location where the paths of two vehicles, or a vehicle and a pedestrian diverge, merge, or cross each other. Figure 2.12 indicates that the typically 32 vehicle-to-vehicle conflict points for a four-leg intersection decreases by 75 % for roundabouts with 8 vehicle-to-vehicle conflict points. It should be noted however that the central island of a roundabout provides an additional hazard that may result in a disproportionately higher number of single-vehicle crashes that would typically occur during periods of low traffic volumes. At traffic signal-controlled intersections many such traffic violations may go unrecorded unless a collision with another vehicle occurs. Priority controlled signs or signalisation can reduce the number of crossing conflicts at a traditional intersection by separating conflicts in space and or time. However, the most severe crashes at intersections occur when there is driver error at a traffic control device designed to separate conflicts by time, for example, a crash due to a vehicle running a red light, or vehicle-pedestrian collisions. Roundabouts, by reducing the number and complexity of driver decisions, have the ability to reduce conflicts through physical, geometric features and is typically more effective than reliance on driver obedience to other more complex traffic control devices such as traffic signals (FHWA 2000: 26).

2.12 Crash risk by road classification

The South African Road Classification and Access Management Manual (TRH 26) (Committee of Transport Officials 2012c) describes road classification based exclusively on their function and the fact that a road that has been built or managed to a particular standard does not mean that it has a particular function. The different road classes are identified according to three primary criteria as follows:

1. The size and significance of the trip generator. Mobility roads link large trip generators and centres of development (rural or urban) while access streets provide access to individual properties and collect and distribute traffic between those properties and mobility roads.
2. The reach of connectivity or travel distance where mobility roads are required for longer travel distances while access roads have much shorter travel distance.
3. Road classification according to the three travel stages, namely: local at the origin, through, and local at the destination. When departing from an origin or arriving at a destination, the travel is local in nature and served by access roads. The travel stage away from the origin or destination is described by travel that is through in nature and provided by mobility roads.

The functional road classification may further be described as follows (eThekwini Municipality 2016: 4):

- Class 1 – Freeways

  These roads are typically freeways with large volumes of traffic and long-distance trips. The geometric characteristics are generally divided, dual carriageways with grade separated intersections, with a 120 km/h design speed and no direct access to properties.

- Class 2 – Arterials

  Major arterial roads support freeways forming the primary road network within an urban area. The physical characteristics are typically divided (dual) carriageways or four lane roads with intersections at grade, signal controlled with 80 km/h to 100 km/h design speed and limited access to properties. Access to properties are often provided by means of parallel service roads.

- Class 3 – Distributors

Minor arterials or distributors distribute traffic between the various major land-use development areas linking arterials and freeways to Class 4 roads. These roads have slightly lower design standards and capacities than major arterials with correspondingly lower design speeds and traffic volumes. Typically accommodates significant Non-Motorised Transport (NMT) volumes.

- Class 4 –Collectors

Collector roads distribute traffic within the residential development areas and provide the main circulation routes within residential areas. The geometric characteristics are typically single carriageway roads two lanes wide. Typically accommodates significant NMT volumes.

- Class 5 – Local Roads

These are local roads which typically provide direct access to residential properties. The physical characteristics are single carriageway roads two lanes or sometimes single lane wide.

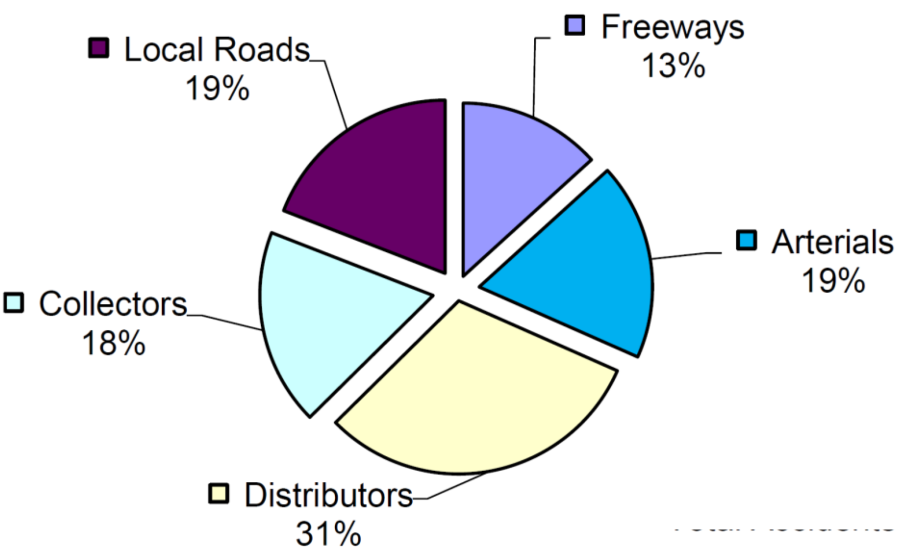

Figure 2.13: Total crash distribution in eThekwini Municipality by road type
Source: eThekwini Municipality (2016: 4)

The crash statistics provided by the Road Accident Statistics and Road Traffic Volumes 2014-2015 report published by the eThekwini Transport Authority (eThekwini Municipality 2016: 5) are shown in Figure 2.13. These statistics indicate that the largest number of crashes occur on Class 3 roads or distributors. The statistics show a distribution that follows a general trend of dissipating or reducing number of accidents as the road function becomes more defined either in terms of mobility or accessibility. It may therefore be deduced that the conflict in terms of road function that occurs when significant levels of mobility and accessibility are accommodated on the same roadway leads to a higher prevalence of crashes, as represented in Table 2.5 below.

Table 2.5: Relationship between road classification and number of crashes

Road Classification Number	Function	Description
Class 1	↑ Mobility	Principal arterial
Class 2		Major arterial
Class 3		Minor arterial
	HIGHEST % OF CRASHES	
Class 4	↓ Access/Activity	Collector street
Class 5		Local street
Class 6		Walkway

It should be noted that even when taking into account the traffic volumes in relation to the number of crashes it appears on cursory examination that the greatest rates of accidents occur on Class 3 roads or roads which are most typically serving both mobility and accessibility needs. It should also be considered and proposed for further investigation that the speed differential between motorised vehicles compared to non-motorised transport (NMT) are factors that contribute to the rate and severity of crashes on Class 3 roads. Speed differentials exacerbate conflict points when viewing crash risk in aspects of both space and time, where risk is increased due to the time that conflict points are exposed to crash risk, for example the speed or time taken for pedestrians to cross roadways. It may also be viewed conversely that despite the highest traffic volumes, freeways pose lower crash risks due to the typically orderly, uniform flow of traffic which also supports driver expectancy and behaviour.

2.13 The economic cost of crashes

The cost of crashes has a negative effect on the South African economy as the total cost of road traffic crashes was estimated to amount to R142.9 billion for 2015, which represented about 3.4 % of the Gross Domestic Product (GDP) (Labuschagne et al. 2017: 474). The distribution of the costs is described in Figure 2.14 below.

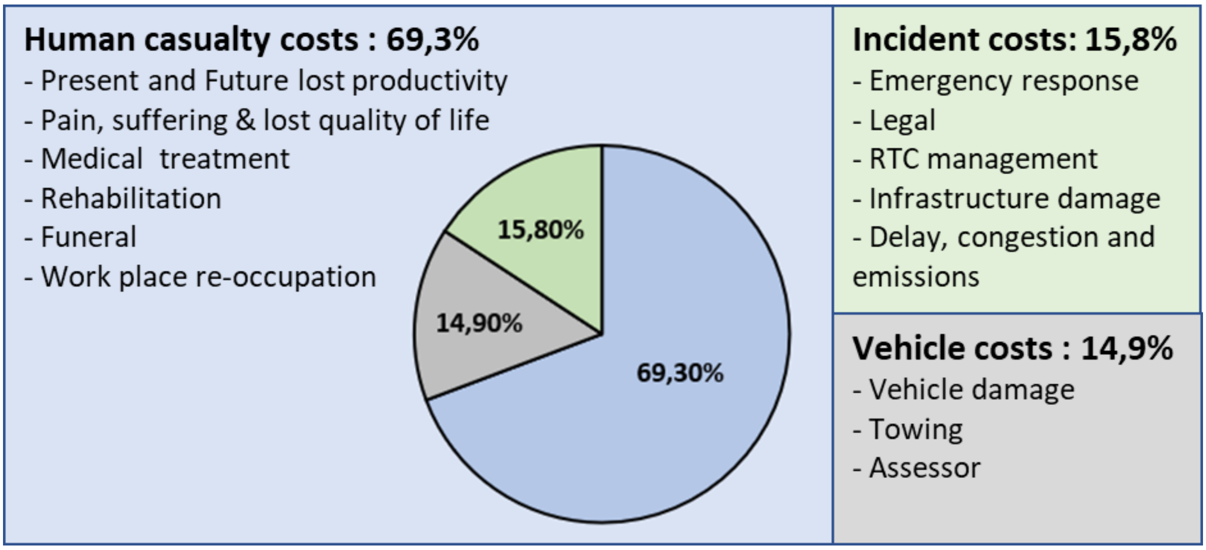

Figure 2.13: The cost of crashes
Source: Adapted from Labuschagne et al. (2017)

Road safety improvement can arise from implementing countermeasures proven to be successful. Due to competition for funding, economic analysis is required in order to compare and rank countermeasures. An effective economic analysis tool is a cost and benefit analysis. A cost metric is a calculation of the investment costs of a countermeasure while a benefit metric is an estimate of the cost savings resulting from crash reductions over a number of years. As a comparison, speed enforcement has a Benefit/Cost (B/C) ratio of between 2.9 to 3.6 therefore should an amount of R1.0 million be invested in effective speed enforcement, an improvement in road safety (measured in terms of crash cost savings) of between R2.9 and R3.6 million could be expected. However, greater returns may be realised by investing R1.0 million rand in an effective (alcohol) drinking and driving campaign with a higher B/C ratio of between 4.7 to 20 which could result in a cost (and life) saving of between R4.7 and R20 million (Labuschagne et al. 2017: 483).

2.14 The effect of economic downturn and recession on crashes

An important factor in the analysis of crash statistics, especially in the current South African economic conditions of low Gross Domestic Product (GDP), is the correlation of economic growth and crashes. Research conducted by the International Transport Forum (2015: 39) describes various factors that contribute to a reduction in crashes during periods of low economic growth. These factors include a reduction in traffic or exposure rates especially decreased kilometres driven of risky vehicle types such as young male drivers and heavy goods vehicles. Economic recession also reduces other risky behaviours by promoting cost saving (slower) economical driving and reduction in alcohol consumption, greatly reducing the risk for speeding and drunk driving related crashes respectively. Although the effect of the economy on accidents and its statistical trends should be accounted for when interpreting the effectiveness of road safety initiatives, it should be noted that the report conducted by the International Transport Forum (2015) is based on research from European countries and does not include developing countries such as South Africa. The results and findings may therefore not correlate fully when applied to developing countries.

2.15 Conclusion

The development of road safety assessment tools for transportation and traffic engineers is a complex subject that involves continuous planning, implementation and evaluation. It is this iterative cycle of plan, do, check, act, that also allows for continuous improvement in the body of literature and the research field of road safety assessments and crash analysis. As part of the planning process, network screening requires that engineers are involved in the collection and analysis of traffic safety data in order to effectively prioritise projects in an often resource limited South African environment. However, to better understand road safety assessments and network screening it is also necessary to delve into both the background literature and detail variables affecting road safety and crash rates in particular. The Safe Systems approach requires that driver error in the causes of crashes does not absolve road authorities from their efforts to reduce the number and severity of accidents.

The literature indicates that the responsibility for road safety lies firmly with road authorities, where the focus should be directed on standards and procedures that proactively address road safety during the full lifecycle and operation of road networks. Best practice guidelines and standards such as the Highway Safety Manual, Road Safety Management Process, and the International Organisation for Standardization, Road Traffic Safety (RTS) Management System ISO 39001 provide the departure point towards the development of more detail road safety assessment procedures. The safe system approach also requires engineers, designers and road authorities to acknowledge that the achievement of high-quality road design often goes beyond minimum standards while also ensuring basic requirements such as adequate sight distance, mitigation or separation of speed variations between the different transport modes and to promote driver and road user expectancy. The literature provides an adequate context to understand crash rates and describes various factors affecting crashes including driver and road user behaviour, intersection conflict points, level of traffic congestion, economic conditions and roadway geometry. Crash analysis by means of crash frequency and crash rates provides valuable quantitative outputs and is an integral component of the road safety process; however, the complexity of crashes is such that adequate engineering judgement is required to ensure the correctness of subsequent actions taken. The comprehensive exploration of literature reveals the latest international and national perspectives on road safety and supports the advancement of road safety knowledge, particularly in the South African context.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Intersections constitute a relatively small portion of the road network; however, intersection related crashes contribute to 20 % of all fatal crashes (FHWA 2013: 6-4). In developing countries, there is a necessity for a paradigm shift from a reactive approach to road safety where investigations are only based on complaints or locations with high crash frequency, to a more proactive approach where road safety is incorporated into all stages of a roadway lifecycle. The proactive approach is supported by both qualitative and quantitative analytical tools. Qualitative tools are typically employed when the intersection is in the planning or design stage and sufficient operational or historical data such as crash rates and traffic counts data are not available. A road safety audit, which is a formal safety performance examination of an existing or future road or intersection by an independent audit team is one such qualitative approach. In addition, qualitative techniques also include:

- Positive guidance review.
- Driver behaviour observation.
- Human factors review.
- Conflict analysis.
- Surrogate measures such as time to collision using traffic simulation models.

These techniques can be used independently or as part of a formal road safety audit process (FHWA 2013: 6-4).

As part of the quantitative approach, the FHWA proposes two key questions in order to select intersections for a detailed safety analysis:

- What is the safety performance of the location in comparison with other similar locations?
- Is the safety performance at the location acceptable or not acceptable?

In the application of quantitative methods, it is important to note that the poor safety performance of an intersection (i.e. a sudden spike in frequency of crashes) during a few months or a year, should not necessarily warrant selection of the intersection for detailed review, because of the probability that the crash frequency will decrease in the next few months. Due to the random nature of crash data this evening out over time is described as “regression to the mean”.

The HSM provides the following quantitative safety performance measures that may be used for the network screening process, listed in order of increasing data requirements (Garber and Hoel 2015: 183):

- Average Annual Crash Frequency.
- Crash Rate.
- Equivalent Property Damage Only (EPDO) Average Crash Frequency.
- Relative Severity Index.
- Critical Rate.
- Excessive Predicted Average Crash Frequency (Using Method of Moments).
- Level of Service of Safety (LOSS).
- Excess Predicted Average Crash Frequency (Using Safety Performance Functions (SPFs)).
- Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment.
- EPDO Average Frequency with EB Adjustment.
- Excess Expected Frequency with EB Adjustment.

3.2 Research design

The extent and scope of this research was governed by the large geographical scale of the CTMM which covers a land area of 6 368 square kilometres. The CTMM stretches approximately 121 km from east to west and 108 km from north to south making it the third largest, by land area, city in the world after New York and Tokyo. The research objectives were therefore to focus on a top down or macro view of road safety using screening methods to effectively identify the highest priority areas for more detailed road safety studies. The data requirements for the study were all available within the CTMM, and due to the large organisational structure, the data resided across various departments.

The primary sources of raw data used for the study were:

- Accident data from the TRAFMAN system.
- Traffic count data from the traffic counting database.
- Road classification data from the ARCGIS system.
- Intersection geometry from the ARCGIS system.
- Intersection control type from the ARCGIS system.

The CTMM Traffic Authority Management Information System (TRAFMAN) is a fully integrated information system for amongst other issues, accidents, traffic contraventions and incidents. The system allows for data of multiple authorities to be captured on the same database which makes it highly suitable for metropolitan, provincial and national authorities in that they can choose to capture data separately or collectively. The data source for the TRAFMAN system originates from the national standardised Accident Report Form (ARF), which, following a traffic accident, is typically completed at a South African Police Service (SAPS) Station. The forms across all SAPS stations Tshwane-wide are then routinely submitted to the CTMM Metro Police Department, where it is captured on the TRAFMAN system. The system is able to generate varied reports including information on the types of accidents as well as the severity of accidents in terms of the classification of injuries or damages. For this study a five-year accident record was used, from January 2014 to December 2018 with a sample of 112 intersections. The intersections were further categorised into five groups according to the type of intersection control, namely: priority controlled, all-way controlled, traffic circle controlled, traffic signal controlled and traffic signal controlled intersections located in the Pretoria Central Business District (CBD).

The 12-hour traffic counts across various Tshwane intersections were obtained from the Intelligent Transport Systems and Traffic Engineering section of the CTMM. The 12-hour traffic counts are routinely conducted as a means of managing the operations and possible upgrades of various traffic signal, traffic circle and traffic sign-controlled intersections across the city. The traffic counts were factored up or down to a base month and year of July 2016. The 12-hour traffic counts were further converted to a 24-hour count by multiplying with a factor of 1.2 and to an annual count by multiplying with a factor of 300 (Aucamp 2014: 36). The traffic count samples were selected based on obtaining a representative distribution of traffic volumes and intersection control types. The data required for road classification, intersection geometry and intersection control type were obtained via the CTMM's ARCGIS geographical information system, as-built records, as well as site inspections where clarity or confirmation was required.

As per recommendations provided by the HSM (Garber and Hoel 2015: 183) and taking into consideration the data available, the most suitable road safety screening methods were determined to be the Equivalent Accident Number (EAN), Crash Frequency, and Crash Rate. The EAN takes into account the severity of an accident by the application of weights dependant on the cost of the accident. As shown in Table 3.1 below, a fatal accident is weighted 12 times that of a damage only or no-injury accident (Aucamp 2014: 38).

Table 3.1: Equivalent Accident Number (EAN)

ACCIDENT SEVERITY	EQUIVALENT ACCIDENT NUMBER
Fatal	12
Serious	8
Slight	3
No Injury	1

The Crash or Accident Frequency made use of five consecutive years of accident data and is represented by the formulae below in Equation 1 and Equation 2:

Equation 1:

$$Crash\ Frequency = \frac{Crashes}{Year} = \frac{\sum Crashes\ over\ 5years}{5\ years}$$

Crash rates are determined on the basis of exposure data, such as traffic volumes and the length of road section being considered. Commonly used rates are Rate per Million of Entering Vehicles (RMEVs) for intersections and Rate per 100 Million Vehicle Kilometres (RMVK) for road segments (Garber and Hoel 2015: 190).

Equation 2:

$$Crash\ Rate\ per\ million\ entering\ vehicles\ (RMEV) = \frac{Crashes\ per\ year \times 1\ 000\ 000}{Annual\ Average\ Daily\ Traffic}$$

As crash rates may be biased and over emphasise intersections with low traffic volumes, it was therefore necessary to compare crash rates for intersections with similar characteristics in terms of road classification, intersection geometry, traffic volumes and intersection control type.

3.3 Method

Statistics is the field of science that involves the collection, analysis and reporting of information that has been sampled from the world around us, where typically the data analysed is a sample or representative subset from a much larger population. The data may further be defined by different levels of measurement described as follows, from the lowest to the highest level of measurement, namely: nominal (categorical/qualitative data), ordinal (ranked data), interval (quantitative data) and ratio (quantitative data) (Smith 2018: 39). Therefore, the count data used in this research can be classified as discrete ratio data.

As the objective is to determine if a statistically significant relationship exists between the two samples, namely of traffic volumes and of accident counts, the appropriate statistical test would include a linear regression analysis. The statistical method is further supported by Rakha et al. (2010: 21) indicating that a least square linear regression model approach can be applied to crash data to develop crash prediction models.

Simple linear regression accounts for a single regressor variable “x” and dependant variable “y”. The linear equation is shown in Equation 3.

Equation 3:

$$y = \beta_0 + \beta_1 x + \epsilon$$

Where,

y = dependant variable (accident counts)

x = independent variable (traffic volumes (ADT))

β_0 = constant or intercept

β_1 = co-efficient or slope of x

ϵ = random error term

The linear regression equation and model as represented above allows for the prediction of new or future observations of "y" (accident counts) corresponding to a specified value for the dependant variable "x" (traffic volumes) (Montgomery and Runger 2014: 434). The two hypotheses proposed for statistical testing in order to confirm either the default position or the relationship between the two variables are, respectively, the null hypothesis and alternative hypothesis which are presented as follows:

$H_{0\ (null)}$: Traffic volume per intersection control type does not affect traffic accidents. The slope co-efficient of traffic volume is zero.

$H_{a\ (alternative)}$: Traffic volume per intersection control type does affect traffic accidents. The slope co-efficient of traffic volume is positive.

The objectives were further described as the statistically significant relationship between the independent variable (IV) which is Average Daily Traffic and the dependant variable (DV) which is either the Accident Frequency or Accident Severity Frequency for the various intersection control types. Simple linear regression and correlation models were developed for the various intersection control types making use of the Statistical Package for the Social Sciences software (SPSS).

As per the objectives, bivariate statistical analysis was conducted for the following intersection control types as listed below, with each including Accident Severity Frequency as an additional analysis:

- Accident Frequency and Average Daily Traffic for all intersection control types combined.
- Accident Frequency and Average Daily Traffic for priority-controlled intersections.
- Accident Frequency and Average Daily Traffic for all-way controlled intersections.
- Accident Frequency and Average Daily Traffic for traffic circle-controlled intersections.
- Accident Frequency and Average Daily Traffic for traffic signal-controlled intersections.
- Accident Frequency and Average Daily Traffic for traffic signal-controlled intersections in the Pretoria Central Business District (CBD).

3.4 Adequacy and significance of the model

The adequacy of the simple linear regression model will involve tests for the goodness of fit of the regression and to further check assumptions by residual analysis, which should indicate residuals as normally distributed. It is important to note that statistically significant relationships between variables do not necessary indicate causation as it is possible to obtain statistical significance among variables which are completely unrelated. Regression relationships in addition are only valid for the regressor variable within the range of the original model data, and is unlikely to be valid if extrapolated too far beyond the original range of the independent variable (Garber and Hoel 2015: 423).

The first step in the statistical process is to complete a correlation analysis to determine whether there exists a relationship between the two variables which would allow for the development of a regression model. The correlation analysis was tested for a 95 % confidence level. The SPSS statistical software makes use of the Pearson product-moment correlation coefficient to quantify the strength and direction of a linear relationship between two random variables.

A perfect correlation of +1 or -1 indicates that the value of one variable can be determined exactly by knowing the value of the other variable, with correlations closest to +1 or -1 indicating the strongest relationship between variables as follows (Cohen 1988: 413):

r = 0.10 to 0.29	or	r = -0.10 to -0.29	Small
r = 0.30 to 0.49	or	r = -0.30 to -0.49	Medium
r = 0.50 to 1.00	or	r = -0.50 to -1.00	Large

The adequacy or quality of the regression model will be determined by the coefficient of determination or R^2 which measures the percentage of the total variation in the dependant variable explained by the regression model, with a small R^2 value indicating that observed values are widely spread around the regression line. Larger values indicate a stronger "goodness of fit" of the model with a value of 1 for example indicating a perfect fit where 100% of the dependant variable is predicted by the independent variable (Montgomery and Runger 2014: 434).

The assessment of the significance of the regression model would include the Analysis of Variance (ANOVA) statistical method. The procedure comprises the f-test where the total variability in the dependant variable is partitioned into meaningful components as the basis of the test. The ANOVA method is further described by its ability to test the null hypothesis and the calculated probability (p-values) of the regression model. Any calculated probabilities or p-values of less than 0.05 are regarded as statistically significant (important) and indicate that the sample adequately represents the entire population. In addition to the ANOVA method, the SPSS software conducts the t-test which is further able to test the hypothesis in terms of the regression model's assumptions, slope, intercept, and error components. The regression model by making use of the resulting coefficients and equation may therefore be used for the prediction of new or future observations. The result would further indicate, for example, that the null hypothesis may be rejected at p-values of less than 0.05 and the alternative hypothesis may then be accepted as true (Montgomery and Runger 2014: 430).

3.5 Limitations

The raw source data while of a good quality presented certain limitations that require noting and further exploration. Human error in any data capturing process is to some extent to be accepted, accounted for, mitigated and then addressed in future research. Limitations encountered in the accident source data, include errors in reporting, capturing as well as a specific lack of capturing of fatal accidents via the SAPS stations. This under-reporting error arises due to SAPS stations retaining all fatal accident files at the police stations as ongoing cases and not submitting these reports to the TRAFMAN data capturers timeously.

In mitigation of these possible errors in fatal accidents this research study includes an analysis of Accident Frequency which accounts for the fatal accident underreporting by not applying weighting factors to the severity of accidents per intersection. It is further reported by Okeowo (2018: 211) that the five factors contributing to anomalies in the typical South African Accident Report (AR) Form are human behavioural characteristics, data collection tool, competence of the personnel, reliability of the data collection procedures and consistency of the validation processes.

The eThekwini Metropolitan Municipality describes similar challenges with regards to accident data, where the following issues are typically encountered (eThekwini Municipality 2012: 37):

- Incompleteness of data where not all information is completed, particularly the location.
- Accident severity is often not followed-up by SAPS and reported to eThekwini (the national directive is 30 days). Follow up is in addition required in relation to mortuary data.
- Many of the accident report forms are kept in dockets at the SAPS and not forwarded to the data capturers.
- Under-reporting occurs primarily with damage only accidents, where members of the public are not insured and resolve cost among themselves, without reporting accidents at the SAPS.

The traffic count data employed in this study was randomly selected across the differing intersection control types and was obtained via the CTMM traffic count database which is expected to be representative of the CTMM road network. It is further noted that South Africa as a developing country is often subjected to numerous road construction projects which makes collecting reliable traffic count data over a 5-year period complicated and requires further analysis of the data and road network to take into account the effects of previous and or ongoing projects.

Traffic growth rates also show variation in terms of the locality of the intersection being studied, where often larger growth rates are shown in previously disadvantaged areas and lower growth rates in more established areas. Conversely, as currently experienced in South Africa over the same 5-year period, the lack or slowing down of economic growth make estimates of previous and future traffic counts problematic.

It is in addition noted that a full CTMM network analysis of intersection saturation levels in terms of traffic volumes divided by capacity (v/c ratios) is beyond the scope of this research. In this regard the identification of saturated intersections and v/c ratios would have been useful in determining more accurate growth rates. In addition, the comparison of traffic volumes and the number of crashes could more accurately be described by taking into account capacity levels and traffic density per intersection studied, where higher traffic density would typically increase the risk and occurrence of crashes. This research study mitigated these limitations to some extent by only using traffic counts on average not older than 2.5 years as well as employing a relatively large sample size of 112 intersections across various intersection control types.

3.6 Conclusion

The road network screening methodologies employed in this study are well established in both national and international literature. The statistical analysis of crash frequency by means of simple linear regression was deemed suitable based on the scope and objectives of this study, as well as the data sources available which did not allow for contributary factors of crashes to be analysed by means of other statistical methods such as multiple linear regression. Additional independent variables contributing to crashes may be analysed by multiple linear regression as part of the diagnosis stage of the extensive Roadway Safety Management process which encompasses; network screening, diagnosis, selection of countermeasures, economic appraisal, prioritisation of projects and safety effectiveness evaluation (Kolody et al., 2014: 2-2). The development of the linear regression equations for the various intersection control types would provide the CTMM and other road authorities with a practical tool for the prediction and analysis of expected accident frequencies for various intersection control types within specified Average Daily Traffic (ADT) volumes.

CHAPTER 4: DATA ANALYSIS AND FINDINGS

4.1 Introduction

It is important to note that crash rates are not dependant solely on any single variable but on the complex interaction of various independent variables. Inconsistencies in crash studies are often due to the selection of variables in isolation of other relevant factors as explained by Garber and Ehrhart (2000: 27) where an example is provided of crash rates that may increase or decrease as the standard deviation of speed increases, dependant in addition to variations of the traffic flow rate. Therefore, cognisance must be taken of the fact that the application of a simple linear regression model involving one independent variable and one dependant variable may not be capable of fully explaining the effect of changes or interactions of the independent variable on the crash rate. However, as a screening method, the simple linear regression model used in this study is suitable as an exploratory “first step” process in identifying and selecting intersections requiring more detailed assessments or audits.

The generation of the linear regression model and data analysis was completed by means of SPSS software, and was in addition compared to a data analysis completed by means of Microsoft Excel software. The results compared favourably and the SPSS results were chosen to be represented in this study. The table comprising the raw and processed data for the 112 intersections included in this study and used as a basis for the linear regression model is presented in Appendix 3. A further concise summary of the aforementioned table is shown below as Table 4.1.

Table 4.1: Summary of preliminary data analysis

Intersection Control Type	Total number per control type	Average Daily Traffic (ADT) (Control Type Average)	Accident Rate (RMEV) (Rate per million of entering vehicles)	Accident Severity Rate (RMEV) (Rate per million of entering vehicles)
All-way Stop Control	20	9535	0,66	0,91
Traffic circle	9	12861	1,02	1,63
Priority Control	31	7708	1,25	2,53
Traffic signal	42	43171	2,35	3,37
Traffic signal – CBD	9	28692	4,70	6,51

The average accident rates per intersection control type shown in Table 4.1 describes a preliminary relationship with traffic volumes. In terms of intersection conflict points it is important to note that traffic circles and traffic signals (in the CBD) are also polar opposites in terms of the number of conflict points. Traffic circles by design typically have 8 vehicle-to-vehicle conflict points. Traffic signals (in the CBD) typically have 32 vehicle-to-vehicle conflict points. However, the CBD environment is further differentiated from intersections in other CTMM areas, in terms of the large number of pedestrians typically present in a CBD which significantly increases conflict points and exposure rates. The accident risk in the CBD environment is further exacerbated by traffic flow which is typically characterised by higher traffic density or number of vehicles per km (vehicles/km) as well as a smaller headway between vehicles which increases the potential for conflicts.

This study has found that an often overlooked aspect in both national and international road safety studies is that pedestrian counts and other NMT modes are not included with motorised traffic counts, in order to calculate a true reflection of exposure in terms of accident rates. The Accident Severity rate as shown in Table 4.1 indicates a trend of increasing accident severity on higher order roads and intersections, due possibly to the larger number of pedestrians present as well as a greater potential for higher speeds and speed differentials, resulting in more severe injuries in the event of an accident.

Table 4.2: Preliminary data analysis – intersection control type as per corresponding ADT

Intersection Control Type	Intersection sliding window selection as per ADT	Total number - control type	Average Daily Traffic (ADT) (Control Type Average)	Accident Rate (RMEV) (Rate per million of entering vehicles)	Accident Severity Rate (RMEV) (Rate per million of entering vehicles)
All-Way Control	Int. Panorama & Alice Int. Panorama & Kestrel Int. Theuns Van Niekerk & Underberg Int. Heuwel & Suid	4	17158	0,80	1,13
Traffic Circle	Int. Braam Pretorius & Dr Swanepoel Int. Lois & Ingersol Int. Maunde & Makaza	3	16548	0,83	1,39
Priority Control	Int. Pierneef & 21st Int. Rooihuiskraal & Kolgans Int. Saxby & Cradock Int. Francis Baard & Farenden	4	18441	0,76	1,63
Traffic Signal	Int. Van Ryneveld & Van Der Spuy Int. Glenwood & Oberon Int. Moot & Hendriks	3	18866	1,31	2,04
Traffic Signal - CBD	Int. Kgosi Mampuru & Bloed Int. Robert Sobukwe & Nelson Mandela Int. Bosman & Jeff Masemola Int. Lilian Ngoyi & Boom	4	19782	5,71	7,73

As shown in Table 4.2, intersections with the most similar level of ADT were identified and averaged for each intersection control type. Intersections were selected by means of a sliding window method assessed over the consecutive ADT counts. As shown in Table 4.2, intersection Accident Severity Rates are indicated as follows with all-way controlled (1.13), traffic circle controlled (1.39) priority controlled (1.63), traffic signal controlled (2.04) and traffic signal CBD (7.73). The increasing accident severity rates are indicative of increasing NMT volumes and of the operating speeds progressively increasing from all-way control, to traffic circles, to priority control and finally to traffic signals with the highest operating speeds. In terms of Accident Rate, the values for all-way controlled (0.80), traffic circle controlled (0.83) and priority controlled (0.76) intersections are almost equivalent and can each be rounded off to a rate of 0.8 accidents per million of entering vehicles (RMEV). The accident severity rate of traffic signals at 2.04 and traffic signals CBD at 7.73 are comparatively larger and may be attributed to significant number of observed pedestrians and other NMT conflicts contributing to accidents. The summarised data in Table 4.1 and Table 4.2 are represented by averages and provide a preliminary view into the accident rates, while the linear regression model will be used to validate the statistical significance of the accident data associated with the various intersection control types.

4.2 Descriptive statistics

To be able to compare different intersection control types, intersections were reclassified as follows as described in Table 4.3 (the one Priority controlled – stop/yield sign (CBD) was coded as missing as it did not form part of any group).

Table 4.3: Grouping of intersection control type

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Priority controlled - stop/yield sign	31	27.7	27.9	27.9
	All way control - stop sign	20	17.9	18.0	45.9
	Traffic circles	9	8.0	8.1	54.1
	Traffic signals	42	37.5	37.8	91.9
	Traffic signals - CBD	9	8.0	8.1	100.0
	Total	111	99.1	100.0	
Missing	System	1	0.9		
Total		112	100.0		

In terms of basic intersection geometry as per Table 4.4, the intersections were mostly four-legged (74.1 %, n = 83). The only intersection that was multi-legged would possibly be grouped with 4-legged intersections for comparison purposes as required.

Table 4.4: Grouping of intersection geometry

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Three-legged	28	25.0	25.0	25.0
	Four-legged	83	74.1	74.1	99.1
	Multi-legged	1	0.9	0.9	100.0
	Total	112	100.0	100.0	

It should be noted that intersection geometry plays a role in accident rates as intersections with a larger number of approaches (for example a four-legged intersection in comparison with a three-legged intersection) is expected to have greater risk or rates of accidents due to the typically larger number of conflict points.

4.3 Inferential statistics

4.3.1 Relationship of accident severity frequency and average daily traffic for all intersection control types combined

The first step of the statistical analysis was by means of a bivariate correlation analysis, to determine whether there is a relationship between the two variables. The following table lists the correlations between pairs of variables for the combined intersection control types, namely: priority control, all-way control, traffic circle, traffic signal and traffic signal - CBD. The correlation analysis as indicated in Table 4.5 below indicates that it is feasible to develop a regression model that will quantify the effect that the independent variable (IV) has on the dependent variable (DV). If there was no correlation between the IV and the DV, then the development of a regression model is not feasible.

Table 4.5: Correlation analysis – accident severity frequency for all intersection groups combined

	Average Daily Traffic (ADT)	Accident Severity Frequency (EAN) (number/year)	Accident Frequency (number/year)
Average Daily Traffic (ADT)	1		
Accident Severity Frequency (EAN) (number/year)	0.769**	1	
Accident Frequency (number/year)	0.772**	0.992**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

The data analysis indicates that ADT correlates well with Accident Frequency at 0.772 as well as Accident Severity Frequency at 0.769, showing a strong positive relationship between the independent variable and dependant variables. The results therefore confirm that it is viable to develop regression models for both Accident Frequency and Accident Severity Frequency. The adequacy or quality of the regression model is represented by the coefficient of determination described as R^2 or R Square as shown in Table 4.6 below. The R Square value indicates that 59.2 % of the total variation in the dependent variable, Accident Severity Frequency, can be explained by the independent variable, Average Daily Traffic. The coefficient of determination of 59.2 % in addition describes a strong “goodness of fit” of the model in terms of how well the actual data fits the estimated values of the model.

Table 4.6: Model summary[b] – accident severity frequency for all intersection groups combined

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.769[a]	0.592	0.588	20.94845551

a. Predictors: (Constant), Average Daily Traffic (ADT)

b. Dependent Variable: Accident Severity Frequency (EAN) (number/year)

The ANOVA or f-test shown in Table 4.7 below indicates that the regression model as a whole is highly significant as the calculated probabilities or p value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted due to the statistically strong relationship between the dependant and independent variable.

Table 4.7: Analysis of variance (ANOVA[a]) (f-test) – accident severity frequency for all intersection groups combined

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	69922.843	1	69922.843	159.336	0.000[b]
	Residual	48272.157	110	438.838		
	Total	118195.000	111			

a. Dependent Variable: Accident Severity Frequency (EAN) (number/year)
b. Predictors: (Constant), Average Daily Traffic (ADT)

Table 4.8 presented below indicates that the relationship between Average Daily Traffic as the independent variable and Accident Severity Frequency as the dependant is significant. The coefficients table further describes how the regression model may be used in terms of prediction. The equation provided allows for prediction by means of calculating the values of the dependent variable based on assumed values of the independent variables and their coefficients. The ‘B’ column in the coefficients table, provides the values of the slope and intercept terms for the regression line as per the following equation:

$$Accident\ Severity\ Frequency = -4.908 + 0.0012*ADT$$

This equation implies that if the ADT increases by 1, then the accident severity frequency increases with 0.0012. The t-test indicates that there is a significant relationship between the independent and dependant variable as the p-value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted.

Table 4.8: Coefficients[a] (t-test) – accident severity frequency for all intersection groups combined

Model		Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	-4.908	3.066		-1.601	0.112		
	Average Daily Traffic (ADT)	0.001	0.000	0.769	12.623	0.000	1.000	1.0

a. Dependent Variable: Accident Severity Frequency (EAN) (number/year)

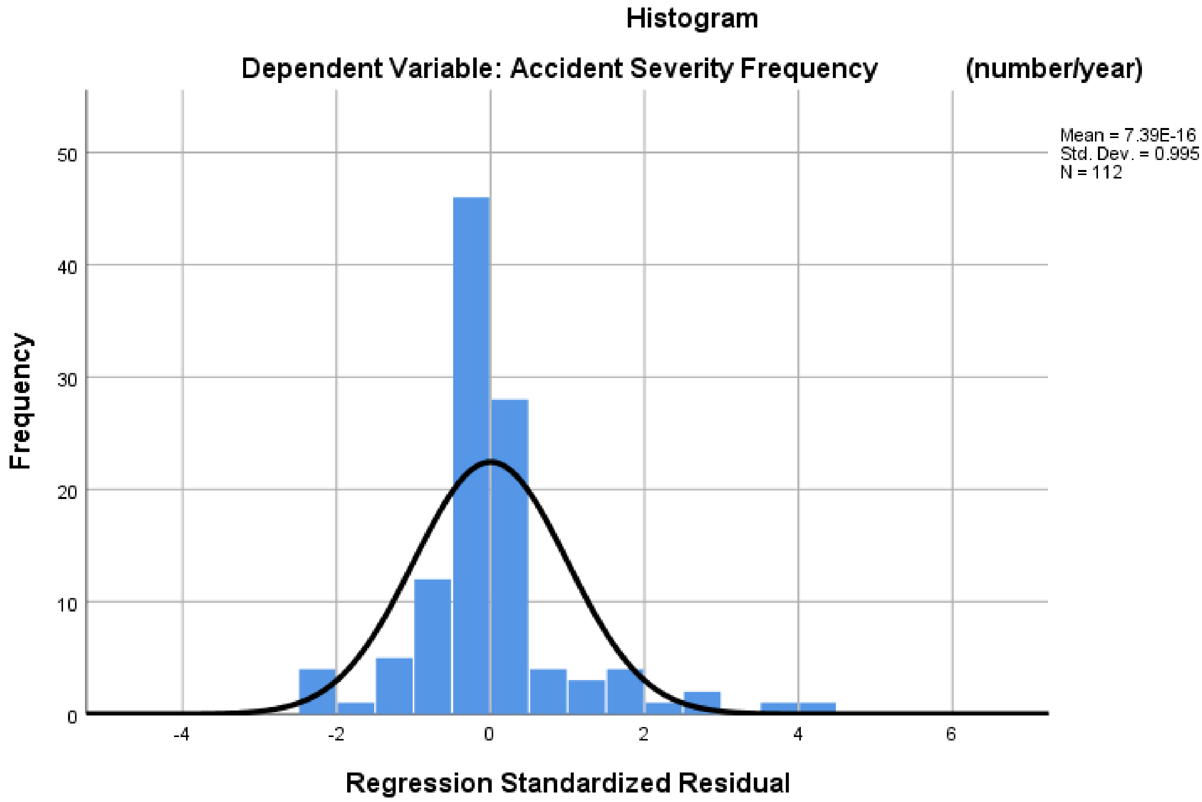

Figure 4.1: Residual analysis – accident severity frequency for all intersection groups combined

An assumption required in estimating the model parameters is that the errors are uncorrelated random variables with a zero mean and constant variance. Tests of hypotheses and interval estimation require that the errors are normally distributed (Montgomery and Runger 2014: 436). As per Figure 4.1, the regression assumption of normally distributed residuals can be considered to have been satisfied since the deviation from normality, visible in the histogram above is not gross.

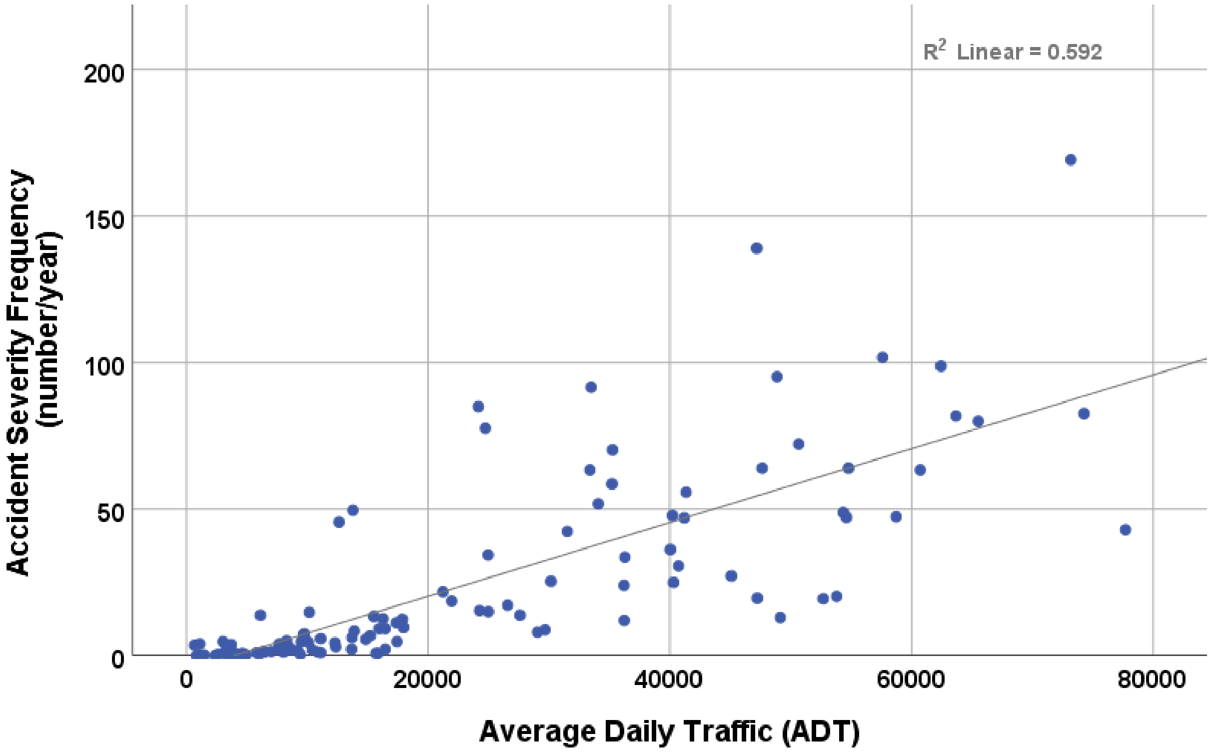

Figure 4.2: Accident severity frequency scatterplot for all intersection groups combined

The scatterplot as represented in Figure 4.2 above shows a positive, moderate linear relationship between the variables. The presence of a wide spread of data points away from the regression line is to be expected considering the somewhat random nature of the subject matter studied which is based on accident data. It is further noted that this graph represents the total grouping of the various intersection control types indicating the general trend of Accident Severity Frequency to increase as Average Daily Traffic increases regardless of the intersection control type. In order to obtain more statistically significant regression models with a better goodness of fit it would therefore be useful to separate or group the data into separate intersection control types.

4.3.2 Relationship of accident frequency and average daily traffic for all intersection control types combined

The adequacy or quality of the regression model is represented by the coefficient of determination described as R^2 or R Square as shown in Table 4.9 below. The R Square value indicates that 59.6 % of the total variation in the dependent variable, Accident Frequency can be explained by the independent variable, Average Daily Traffic. The coefficient of determination of 59.6 % in addition describes a strong "goodness of fit" of the model in terms of how well the actual data fits the estimated values of the model.

Table 4.9: Model summary[b] – accident frequency for all intersection groups combined

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.772[a]	0.596	0.593	15.15598128

a. Predictors: (Constant), Average Daily Traffic (ADT)

b. Dependent Variable: Accident Frequency (number/year)

The ANOVA or f-test shown in Table 4.10 below indicates that the regression model as a whole is highly significant as the calculated probabilities or p-value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted due to the statistically strong relationship between the dependant and independent variable.

Table 4.10: Analysis of variance (ANOVA[a]) (f-test) – accident frequency for all intersection groups combined

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	37344.232	1	37344.232	162.576	0.000[b]
	Residual	25267.415	110	229.704		
	Total	62611.647	111			

a. Dependent Variable: Accident Frequency (number/year)
b. Predictors: (Constant), Average Daily Traffic (ADT)

Table 4.11 presented below indicates that the relationship between Average Daily Traffic as the independent variable and Accident Frequency as the dependant is significant. The coefficients table further describes how the regression model may be used in terms of prediction. The equation provided allows for prediction by means of calculating the values of the dependent variable based on assumed values of the independent variables and their coefficients. The 'B' column in the coefficients table, provides the values of the slope and intercept terms for the regression line as per the following equation:

$$Accident\ Frequency = -4.429 + 0.0009 * ADT$$

This equation implies that if the ADT increases by 1, then the accident severity frequency increases with 0.0009. The t-test indicates that there is a significant relationship between the independent and dependant variable as the p value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted.

Table 4.11: Coefficients[a] (t-test) – accident frequency for all intersection groups combined

Model		**Unstandardised Coefficients**		**Standardised Coefficients**			**Collinearity Statistics**	
		B	**Std. Error**	**Beta**	**t**	**Sig.**	**Tolerance**	**VIF**
1	(Constant)	-4.429	2.218		-1.997	0.048		
	Average Daily Traffic (ADT)	0.001	0.000	0.772	12.751	0.000	1.000	1.0

a. Dependent Variable: Accident Frequency (number/year)

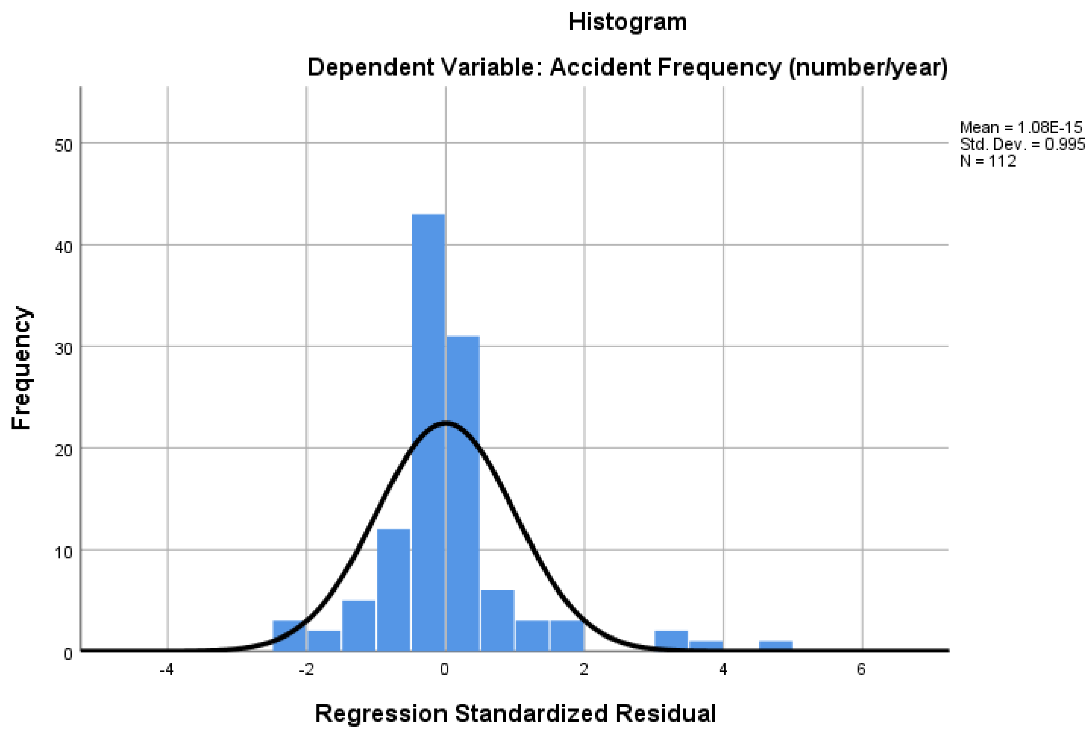

Figure 4.3: Residual analysis – accident frequency for all intersection groups combined

As per Figure 4.3 above, the regression assumption of normally distributed residuals can be considered to have been satisfied since the deviation from normality visible in the histogram above is not excessive.

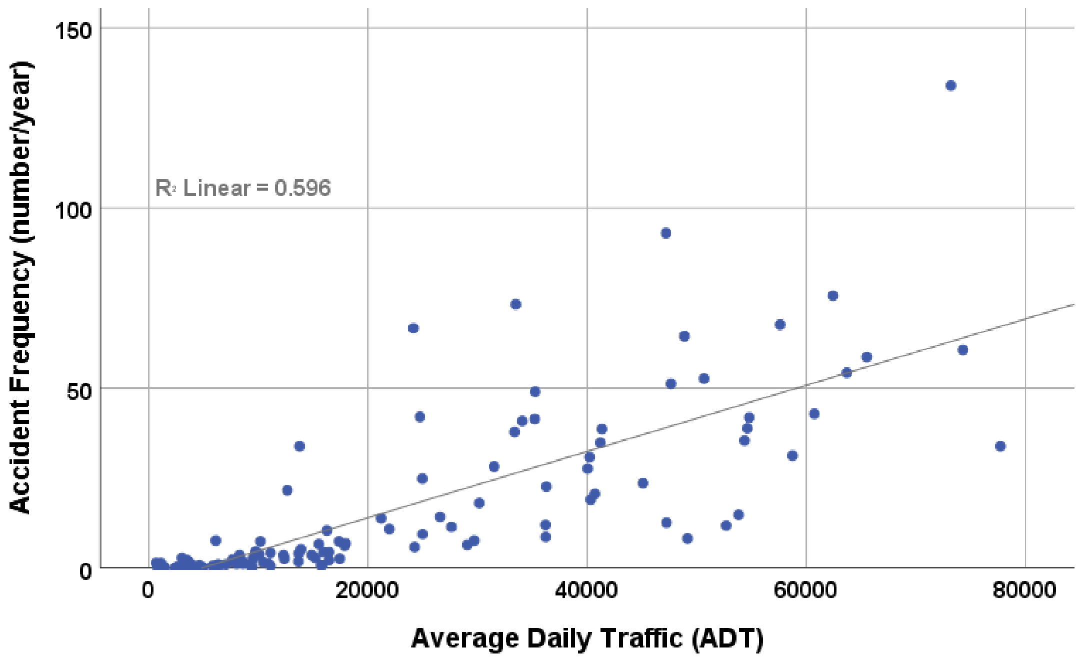

Figure 4.4: Accident frequency scatterplot for all intersection groups combined

The scatterplot as represented in Figure 4.4 above shows positive, moderate linear relationship between the variables. The presence of outliers is to be expected considering the somewhat random nature of the subject studied which is based on accident data. It is further noted that this graph represents the total grouping of the various intersection control types indicating that the general trend of Accident Frequency is to increase as Average Daily Traffic increases regardless of the intersection control type. In order to develop greater statistically significant regression models with a better goodness of fit it would therefore be useful to separate or group the data into separate intersection control types.

4.3.3 Relationship of accident severity frequency and average daily traffic for the individual intersection control types

Table 4.12 below lists the correlations between pairs of variables for the individual intersection control types, namely: priority control, all-way control, traffic circle, traffic signal and traffic signal (CBD). The correlation analysis indicates that it is feasible to develop a regression model for all intersection types except for traffic circles and traffic signals (CBD). Traffic circles indicate a weak correlation of 25 % and 27.1 % with Accident Frequency and Accident Severity Frequency respectively, while traffic signals (CBD) presents a weak correlation of 14.9 % and 20.2 % with Accident Frequency and Accident Severity Frequency respectively. The weak correlations may be attributed to the smaller sample size available for these intersection control types. Future research will require increased sample sizes for the intersection control types of traffic circles and traffic signals (CBD) in order to produce viable linear regression models.

Table 4.12: Correlation analysis – accident severity frequency for individual intersection control types

Intersection control type		Average Daily Traffic (ADT)	Accident Severity Frequency (EAN) (number/year)	Accident Frequency (number/year)
Priority controlled - stop/yield sign	Average Daily Traffic (ADT)	1		
	Accident Severity Frequency	0.622**	1	
	Accident Frequency	0.590**	0.971**	1
All way control - stop sign	Average Daily Traffic (ADT)	1		
	Accident Severity Frequency	0.865**	1	
	Accident Frequency	0.849**	0.998**	1
Traffic circles	Average Daily Traffic (ADT)	1		
	Accident Severity Frequency	0.271	1	
	Accident Frequency	0.25	0.952**	1
Traffic signals	Average Daily Traffic (ADT)	1		
	Accident Severity Frequency	0.634**	1	
	Accident Frequency	0.661**	0.989**	1
Traffic signals - CBD	Average Daily Traffic (ADT)	1		
	Accident Severity Frequency	0.202	1	
	Accident Frequency	0.149	0.982**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

The adequacy or quality of the regression model is represented by the coefficient of determination described as R^2 or R Square as shown in Table 4.13 below. The R Square value for priority-controlled intersections indicates that 38.7 % of the total variation in Accident Severity Frequency can be explained by Average Daily Traffic. Similarly, all-way controlled and traffic signal-controlled intersections provide values of 74.9 % and 40.2 % respectively. In terms of comparison with the combined group model, it may be inferred that a larger sample size may further increase the strength of the coefficient of determination.

Table 4.13: Model summary[b] – accident severity frequency for individual intersection control types

Intersection control type (basic 5)	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Priority controlled - stop/yield sign	1	0.622[a]	0.387	0.366	3.84220512
All way control - stop sign	1	0.865[a]	0.749	0.735	5.96714790
Traffic circles	1	0.271[a]	0.073	-0.059	3.42091309
Traffic signals	1	0.634[a]	0.402	0.387	29.34512186
Traffic signals - CBD	1	0.202[a]	0.041	-0.096	28.14564554

a. Predictors: (Constant), Average Daily Traffic (ADT)
b. Dependent Variable: Accident Severity Frequency (EAN) (number/year)

As shown below in Table 4.14 the regression model is highly significant in the priority controlled group (F(1) = 18.313, p < 0.001), the all-way control group (F(1) = 53.703, p < 0.001) and the traffic signals group (F(1) = 26.882, p < 0.001). The f-test therefore indicates that the regression models as a whole are highly significant as the calculated probabilities or p-value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted due to the statistically strong relationship between the dependant and independent variable.

Table 4.14: Analysis of variance (ANOVA[a]) (f-test) – accident severity frequency for individual intersection control types

Intersection control type (basic 5)	Model		Sum of Squares	df	Mean Square	F	Sig.
Priority controlled - stop/yield sign	1	Regression	270.346	1	270.346	18.313	0.000[b]
		Residual	428.114	29	14.763		
		Total	698.459	30			
All way control - stop sign	1	Regression	1912.187	1	1912.187	53.703	0.000[b]
		Residual	640.923	18	35.607		
		Total	2553.110	19			
Traffic circles	1	Regression	6.481	1	6.481	0.554	0.481[b]
		Residual	81.919	7	11.703		
		Total	88.400	8			
Traffic signals	1	Regression	23148.976	1	23148.976	26.882	0.000[b]
		Residual	34445.447	40	861.136		
		Total	57594.423	41			
Traffic signals - CBD	1	Regression	236.518	1	236.518	0.299	0.602[b]
		Residual	5545.242	7	792.177		
		Total	5781.760	8			

a. Dependent Variable: Accident Severity Frequency (EAN) (number/year)
b. Predictors: (Constant), Average Daily Traffic (ADT)

Table 4.15 presented below indicates that the relationship between Average Daily Traffic and Accident Severity Frequency is significant for priority controlled, all-way controlled and traffic signal-controlled intersections. The equations for the aforementioned intersections imply that if the ADT increases by 1, then the accident severity frequency increases with 0.0005, 0.0012 and 0.0014 respectively. The t-test in addition indicates that there is a significant relationship between the independent and dependant variable as the p-value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted.

Table 4.15: Coefficients[a] (t-test) – accident severity frequency for individual intersection control types

Intersection control type (basic 5)		Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tol.	VIF
a. Priority controlled - stop/yield sign	(Constant)	0.314	1.145		0.274	0.786		
	Average Daily Traffic (ADT)	0.001	0.000	0.622	4.279	0.000	1.0	1.0
b. All way control - stop sign	(Constant)	-6.882	2.095		-3.286	0.004		
	Average Daily Traffic (ADT)	0.001	0.000	0.865	7.328	0.000	1.0	1.0
c. Traffic circles	(Constant)	2.598	4.799		0.541	0.605		
	Average Daily Traffic (ADT)	0.000	0.000	0.271	0.744	0.481	1.0	1.0
d. Traffic signals	(Constant)	-13.893	12.525		-1.109	0.274		
	Average Daily Traffic (ADT)	0.001	0.000	0.634	5.185	0.000	1.0	1.0
e. Traffic signals - CBD	(Constant)	35.681	31.887		1.119	0.300		
	Average Daily Traffic (ADT)	0.001	0.001	0.202	0.546	0.602	1.0	1.0

a. Dependent Variable: Accident Severity Frequency (EAN) (number/year)

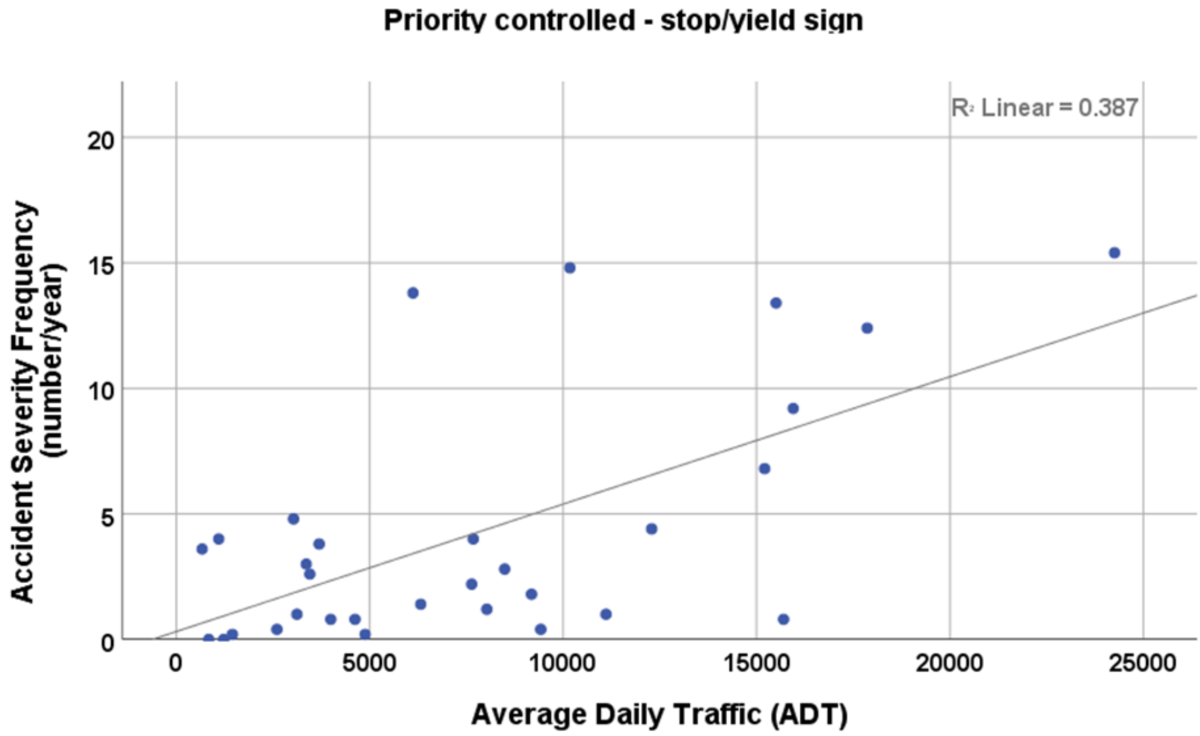

Figure 4.5: Accident severity frequency scatterplot for priority controlled intersections

The scatterplot as represented in Figure 4.5 above shows a positive, moderate linear relationship between the variables for priority controlled intersections.

The equation for the regression line is presented as follows:

$$Accident\ Severity\ Frequency = 0.314 + 0.0005*ADT$$

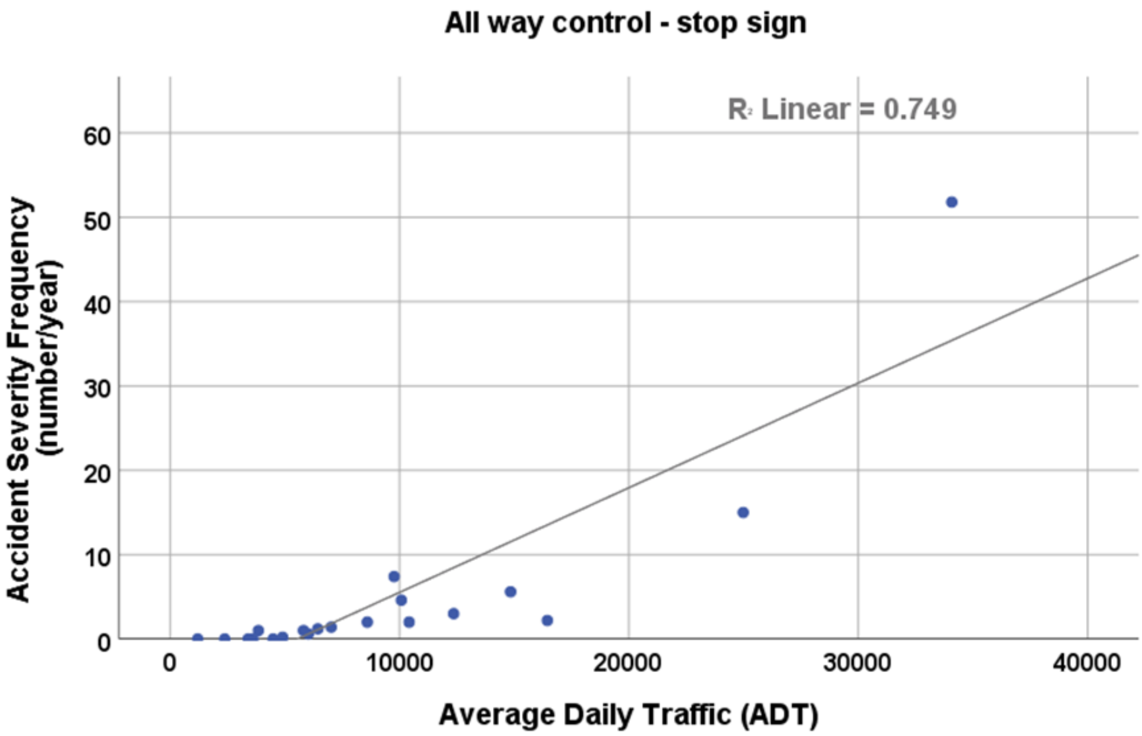

Figure 4.6: Accident severity frequency scatterplot for all-way controlled intersections

The scatterplot as represented in Figure 4.6 above shows a positive, moderate linear relationship between the variables for all-way controlled intersections. It is also noted that due to all way intersection controls being typically employed on lower order roads, the limited range of the independent variable (ADT) typically reflects lower traffic volumes. The limited range of the independent variable supports a closer grouping of data points around the regression line, which is however skewed by intersections greater than 20 000 ADT. A stronger goodness of fit may be achieved by developing separate regression models for ADT values within specified ranges, subject however to the availability of data.

The equation for the regression line is presented as follows:

$$Accident\ Severity\ Frequency = -6.882 + 0.0012*ADT$$

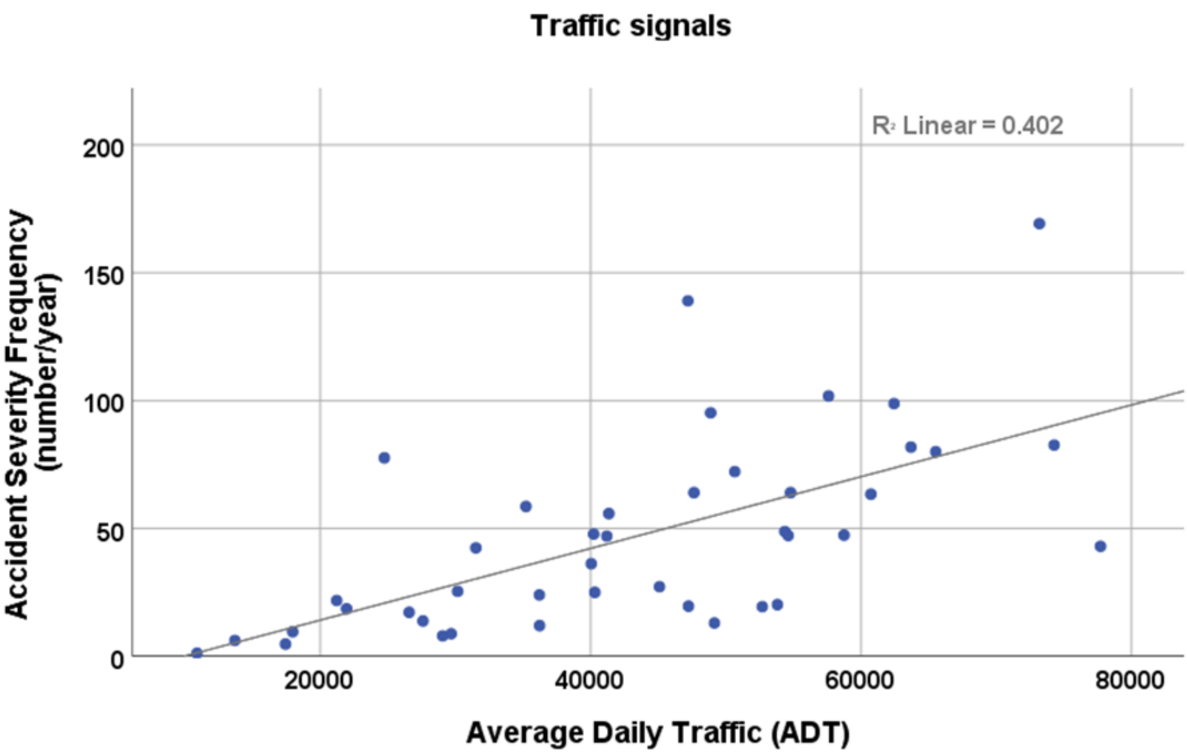

Figure 4.7: Accident severity frequency scatterplot for traffic signal controlled intersections

The scatterplot as represented in Figure 4.7 above shows a positive, moderate linear relationship between the variables for traffic signal controlled intersections. In comparison with other intersection control types, traffic signal controlled intersections shows that for each increase of ADT by 1, there is a relatively greater increase in accident severity frequency of 0.0014. As traffic signals typically serve higher order roads, this may partly be due to factors such as greater speed differentials between the different modes of transport as well as an increased volume of pedestrians and other NMT modes.

The equation for the regression line is presented as follows:

$$Accident\ Severity\ Frequency = -13.893 + 0.0014*ADT$$

4.3.4 Relationship of accident frequency and average daily traffic for the individual intersection control types

The adequacy or quality of the regression model is represented by the coefficient of determination described as R Square as shown in Table 4.16 below. The R Square value for priority-controlled intersections indicates that 34.8 % of the total variation in Accident Frequency can be explained by Average Daily Traffic. Similarly, all-way controlled intersections and traffic signal controlled intersections provides values of 72.1 % and 43.6 % respectively. In terms of comparison with the combined group model, it may be inferred that a larger sample size may further increase the strength of the coefficient of determination.

Table 4.16: Model summary[b] – accident frequency for individual intersection control types

Intersection control type (basic 5)	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Priority controlled - stop/yield sign	1	0.590[a]	0.348	0.325	1.86690155
All way control - stop sign	1	0.849[a]	0.721	0.706	4.89629119
Traffic circles	1	0.250[a]	0.062	-0.071	2.00300796
Traffic signals	1	0.661[a]	0.436	0.422	20.79565795
Traffic signals - CBD	1	0.149[a]	0.022	-0.117	22.64295725

a. Predictors: (Constant), Average Daily Traffic (ADT)

b. Dependent Variable: Accident Frequency (number/year)

As shown below in Table 4.17 the regression model is highly significant in the priority controlled group ($F(1) = 15.446$, $p < 0.001$), the all-way control group ($F(1) = 46.616$, $p < 0.001$) and the traffic signals group ($F(1) = 30.974$, $p < 0.001$). The f-test therefore indicates that the regression model as a whole is highly significant as the calculated probabilities or p-value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted due to the statistically strong relationship between the dependant and independent variable.

Table 4.17: Analysis of variance (ANOVA[a]) (f-test) – accident frequency for individual intersection control types

Intersection control type (basic 5)	Model		Sum of Squares	df	Mean Square	F	Sig.
Priority controlled - stop/yield sign	1	Regression	53.834	1	53.834	15.446	0.000[b]
		Residual	101.074	29	3.485		
		Total	154.908	30			
All way control - stop sign	1	Regression	1117.546	1	1117.546	46.616	0.000[b]
		Residual	431.526	18	23.974		
		Total	1549.072	19			
Traffic circles	1	Regression	1.871	1	1.871	0.466	0.517[b]
		Residual	28.084	7	4.012		
		Total	29.956	8			
Traffic signals	1	Regression	13395.104	1	13395.104	30.974	0.000[b]
		Residual	17298.376	40	432.459		
		Total	30693.480	41			
Traffic signals - CBD	1	Regression	81.538	1	81.538	0.159	0.702[b]
		Residual	3588.925	7	512.704		
		Total	3670.462	8			

a. Dependent Variable: Accident Frequency (number/year)
b. Predictors: (Constant), Average Daily Traffic (ADT)

Table 4.18 presented below indicates that the relationship between Average Daily Traffic and Accident Frequency is significant for priority controlled, all-way controlled and traffic signal controlled intersections. The equations for the aforementioned intersections imply that if the ADT increases by 1, then the accident frequency increases with 0.0002, 0.0009 and 0.0011 respectively. The t-test in addition indicates that there is a significant relationship between the independent and dependant variable as the p-value is less than 0.001. This indicates that the null hypothesis can be rejected and the alternative hypothesis can be accepted.

Table 4.18: Coefficients[a] (t-test) – accident frequency for individual intersection control types

Intersection control type (basic 5)		Unstandardised Coefficients		Standardised Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tol.	VIF
a. Priority controlled - stop/yield sign	(Constant)	0.474	0.557		0.851	0.402		
	Average Daily Traffic (ADT)	0.0002	0.000	0.590	3.930	0.000	1.0	1.0
b. All way control - stop sign	(Constant)	-5.366	1.719		-3.122	0.006		
	Average Daily Traffic (ADT)	0.001	0.000	0.849	6.828	0.000	1.0	1.0
c. Traffic circles	(Constant)	1.914	2.810		0.681	0.518		
	Average Daily Traffic (ADT)	0.000	0.000	0.250	0.683	0.517	1.0	1.0
d. Traffic signals	(Constant)	-13.049	8.876		-1.470	0.149		
	Average Daily Traffic (ADT)	0.001	0.000	0.661	5.565	0.000	1.0	1.0
e. Traffic signals - CBD	(Constant)	27.867	25.653		1.086	0.313		
	Average Daily Traffic (ADT)	0.000	0.001	0.149	0.399	0.702	1.0	1.0

a. Dependent Variable: Accident Frequency (number/year)

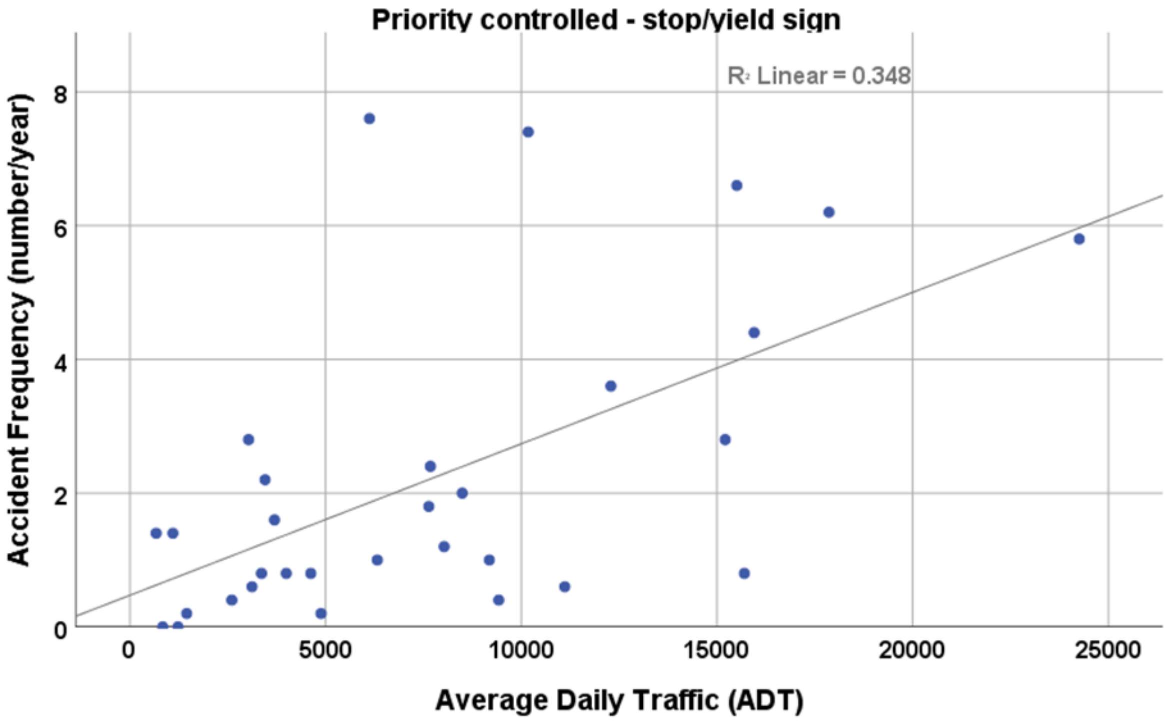

Figure 4.8: Accident frequency scatterplot for priority controlled intersections

The scatterplot as represented in Figure 4.8 above shows a positive, moderate linear relationship between the variables for priority-controlled intersections. The existence of a relatively wider spread of data is to be expected considering the random nature of accident data.

The equation for the regression line is presented as follows:

$$Accident\ Frequency = 0.474 + 0.0002*ADT$$

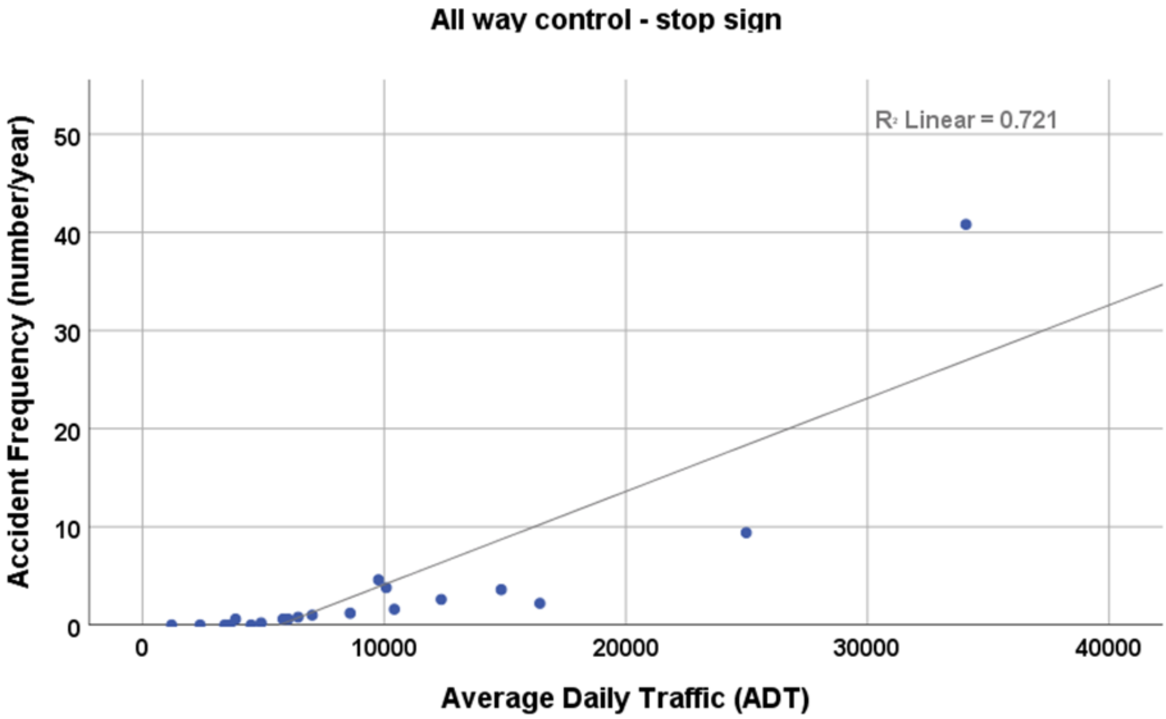

Figure 4.9: Accident frequency scatterplot for all-way controlled intersections

The scatterplot as represented in Figure 4.9 above shows a positive, moderate linear relationship between the variables for priority-controlled intersections. As with accident severity frequency it is again noted that due to all-way intersection controls being typically employed on lower order roads, the limited range of the independent variable (ADT) typically reflects lower traffic volumes. The limited range of the independent variable supports a closer grouping of data points around the regression line, which is however skewed by intersections greater than 20 000 ADT. A stronger goodness of fit may be achieved by developing separate regression models for ADT values within specified ranges, subject however to the availability of data

The equation for the regression line is presented as follows:

$$Accident\ Frequency = -5.366 + 0.0009*ADT$$

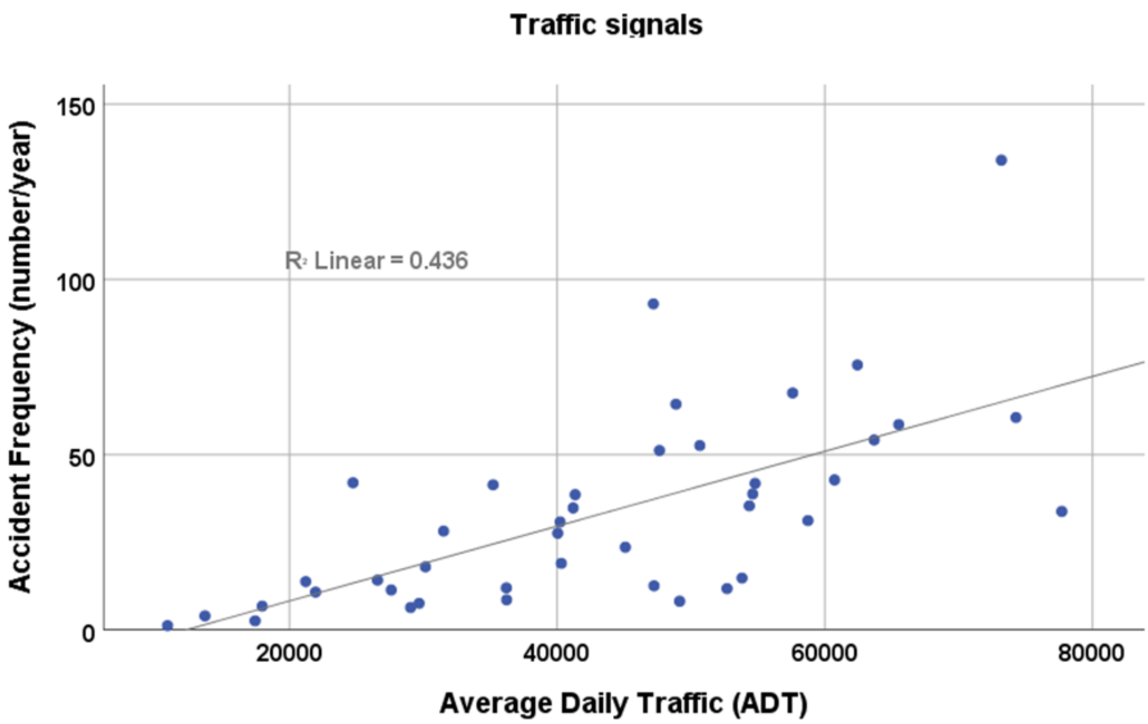

Figure 4.10: Accident frequency scatterplot for traffic signal controlled intersections

The scatterplot as represented in Figure 4.10 above shows a positive, moderate linear relationship between the variables for priority-controlled intersections. The relatively wide spread of data points is to be expected considering the random nature of typical accident data. A stronger goodness of fit may be achieved by developing separate regression models for ADT values within specified ranges, subject however to the availability of data

The equation for the regression line is presented as follows:

$$Accident\ Frequency = -13.049 + 0.0011*ADT$$

4.4 Conclusion

The linear regression equations generated for the priority-controlled intersections, all-way controlled intersections and traffic signal controlled intersections provide a newfound technique for the CTMM in assessing and prioritising road safety interventions. The results do however indicate that a larger sample size is required for traffic circles and traffic signals (in the CBD) in order to develop viable linear regression models for these intersection control types. The higher accident frequencies as shown for traffic signal controlled intersections appear to be attributed to a larger number of pedestrians, a greater number of potential conflict points, and speed differentials between motorised and NMT transport modes. As pedestrian counts were not available and are typically not included in crash rate analysis, it is likely that the higher accident rates are indicative of these hidden figures. For this reason, a key finding is that future crash rate research should include comprehensive, classified traffic counts that include all modes of transport including pedestrians.

The findings further implicitly reveal the importance of intersection conflict points as a potentially large contributing variable in crash rate analysis and it is therefore recommended that future research include intersection geometry, lane layout and conflict point analysis. It is further noted that traffic signal controlled intersections are typically implemented on Class 3 roads which is the interface between providing the conflicting functions of both mobility and access. The findings are supported by the eThekwini Transport Authority report (eThekwini Municipality 2016: 5) which indicates that the majority of accidents occur on Class 3 roads. The findings have offered valuable perspectives, analytical tools, and limitations in terms of practical crash data analysis. The linear regression analysis indicates that the strong correlations between traffic volumes (ADT), accident frequency and accident severity frequency may be further strengthened by means of increased sample sizes, specifically for the intersection control type sub-groups.

CHAPTER 5: CONCLUSION

In the South African context, the literature study has shown that further research is required from municipalities and other spheres of government in terms of road safety and accident studies in particular. Internationally based standards and research, while providing an excellent framework for new road safety research, may not always be applicable to the South African road network, where research outcomes may be affected by differences in driver behaviour, economic and developmental factors, as well as roadway and environmental conditions. The conclusion of the research process has uncovered valuable new insights not alluded to in the literature review.

The data analysis confirms that the alternative hypothesis can be accepted, namely: *traffic volume per intersection control type does affect traffic accidents, where the slope co-efficient of traffic volume is positive*. The results further describe that intersection conflict points play a significant role in the number and severity of accidents recorded. In this regard intersections with high pedestrian volumes and other NMT modes contribute significantly to greater road safety risks. In terms of average crash rates, the results indicate similar accident rates of approximately 0.8 RMEV for priority controlled, all way stop controlled and traffic circle controlled intersections. This accident rate thereafter almost doubles to 1.31 RMEV for traffic signal controlled intersections. The highest accident rates are however for traffic signal controlled intersections in the Pretoria CBD which are more than four times the rate for “non-CBD” traffic signals at 5.71 RMEV. In addition to high pedestrian volumes the non-uniform, sometimes unpredictable driver and road user behaviour exacerbates the high accident rates shown in the Pretoria CBD. This effect is also supported by statistics which describe road classification and the competing functions of mobility and access as increasing the risk of accidents. In this regard, the largest number of accidents are recorded on Class 3 roads, which is the interface between mobility and access, thus accommodating a diverse mix of activities and transport modes both motorised and non-motorised.

The linear regression equation and model as developed through this study allows for the prediction of new or future observations of “y” (accident counts) corresponding to a specified value for the dependent variable “x” (traffic volumes). The linear regression equations will enable CTMM officials and other researchers to analyse, predict, screen and prioritise intersections for more detailed road safety assessments or audits. In this manner scarce municipal funds can be allocated to high benefit but low cost projects that can lead to a greater reduction in road accidents. The cost-benefit prioritisation enables the overall strategy of proactively managing road safety on an objective basis rather than a reactive, inefficient “fire-fighting” approach.

CHAPTER 6: RECOMMENDATIONS

A preliminary sensitivity analysis of the linear regression equations reveals that in order to achieve greater accuracy in accident frequency predictions, it is recommended that equations for the individual intersection control types need to be used, as this will provide more precise results in predicting accident frequencies compared to the equations for the combined intersection control types. A further recommendation for future research is to increase the sample size for the individual intersection control types, in this instance specifically for traffic circles and traffic signals (CBD), in order to develop significant regression models.

The research outcomes highlight the high number of NMT and pedestrian fatalities and accordingly for road safety strategies to focus interventions on NMT accidents and fatalities. It is proposed that road safety screening processes specifically target high pedestrian volume locations such as NMT corridors, schools, commuter nodes and public transport routes. Non-Motorised Transport Masterplans should be routinely updated and should incorporate detailed road safety screening processes including making use of linear regression models as developed in this study. In addition, it is proposed that a CTMM management structure be developed to allow for the implementation of proactive road safety measures and for adequate performance monitoring. It is recommended that projects and performance scorecards should specifically include measures such as the number of accidents and fatalities reduced annually as part of departmental Key Performance Indicators (KPIs). In addition, the effect of NMT modes, especially pedestrian volumes, should be accounted for in future studies by ensuring that all classified traffic counts include discrete counts for all NMT modes of transport. Road safety strategies should emphasise NMT, and pedestrians in particular, as vulnerable road users account for the highest number of road fatalities across all modes of transport.

In addition, further data analysis is required to include the effects of LOS on accident rates and the role of saturated intersections as contributing to higher accidents rates, while lower volume/capacity ratios during off peak periods may lead to lower number of accidents but with higher severity due to the typical higher operating speeds. It is further recommended that multiple linear regression models be considered to measure and quantify additional variables including the effect of intersection conflict points and traffic volumes on accident frequency. Intersection control types should further be differentiated and analysed in terms of their geometric features, for example lane widths, sight distance and road alignment, in order to compare the effect of minimum standards to more cushioning, substantive standards in terms of reducing the number and severity of accidents.

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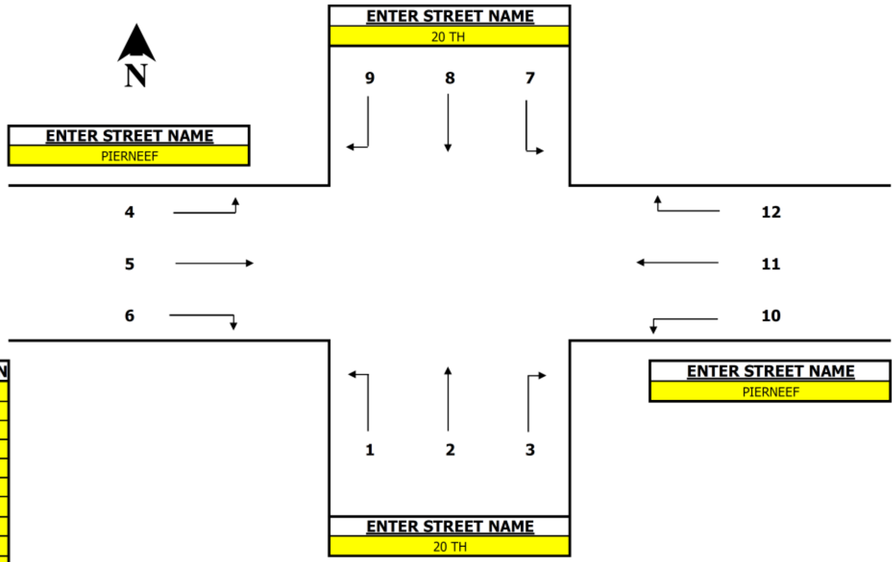
APPENDICES

Appendix 1: Traffic count sample – Intersection of Pierneef Street and 20th Street

DATE:
02 September 2016

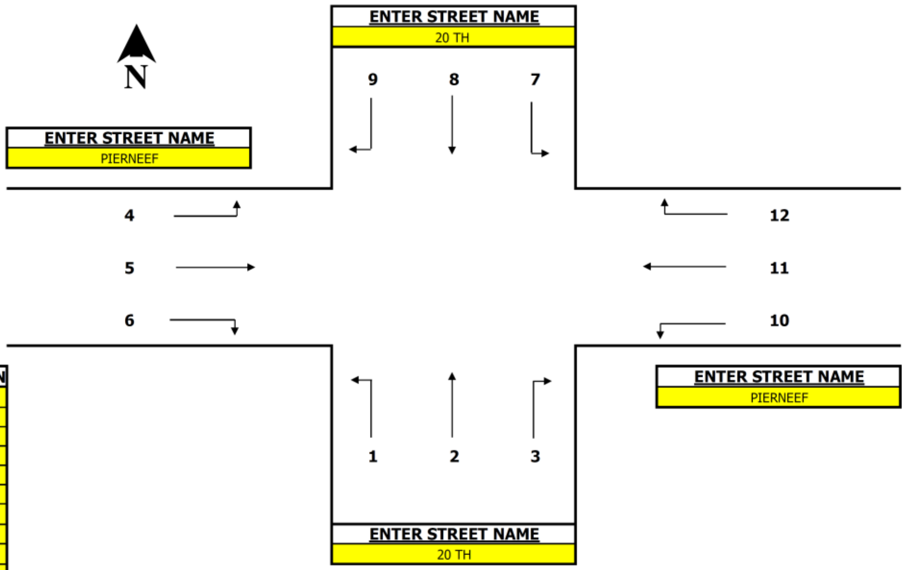


COUNTERS	DIRECTION
MABINA	2
MABINA	4
MABINA	5
MABINA	6
MATHEBULA	1
MATHEBULA	7
MATHEBULA	8
MATHEBULA	9
BALOYI	3
BALOYI	10
BALOYI	11
BALOYI	12

TRAFFIC COUNTS

TIME	MOVEMENT												
	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
06:00 TO 06:15	0	0	0	0	131	1	1	0	2	0	146	0	
06:15 TO 06:30	0	0	1	1	158	2	3	0	2	2	162	1	
06:30 TO 06:45	1	2	1	2	134	1	2	1	1	0	193	0	
06:45 TO 07:00	1	0	2	1	129	1	3	0	1	1	351	0	
TOTAL	**2**	**2**	**4**	**4**	**552**	**5**	**9**	**1**	**6**	**3**	**852**	**1**	**1441**
07:00 TO 07:15	1	0	3	2	177	0	1	0	1	2	433	0	
07:15 TO 07:30	0	0	1	0	126	0	0	0	2	1	476	0	
07:30 TO 07:45	0	2	1	0	110	1	2	0	1	1	519	0	
07:45 TO 08:00	1	0	0	0	108	0	0	1	0	0	405	0	
TOTAL	**2**	**2**	**5**	**2**	**521**	**1**	**3**	**1**	**4**	**4**	**1833**	**0**	**2378**
08:00 TO 08:15	0	0	1	1	151	1	0	0	1	0	126	1	
08:15 TO 08:30	1	0	0	2	116	0	3	0	2	0	120	0	
08:30 TO 08:45	1	0	1	4	79	0	0	0	1	1	146	0	
08:45 TO 09:00	0	1	1	1	131	3	0	0	2	1	92	0	
TOTAL	**2**	**1**	**3**	**8**	**477**	**4**	**3**	**0**	**6**	**2**	**484**	**1**	**991**
09:00 TO 09:15	1	0	2	1	122	0	1	0	0	1	90	0	
09:15 TO 09:30	0	0	0	0	97	0	0	0	0	0	81	0	
09:30 TO 09:45	1	0	1	0	83	0	0	1	0	0	84	0	
09:45 TO 10:00	0	0	0	0	79	0	0	0	0	0	82	0	
TOTAL	**2**	**0**	**3**	**1**	**381**	**0**	**1**	**1**	**0**	**1**	**337**	**0**	**727**
10:00 TO 10:15	1	0	0	0	86	0	0	0	0	0	87	0	
10:15 TO 10:30	0	0	1	5	73	1	1	0	4	0	57	2	
10:30 TO 10:45	0	0	0	4	125	0	1	0	0	1	61	0	
10:45 TO 11:00	0	0	2	1	126	0	0	0	0	0	92	0	
TOTAL	**1**	**0**	**3**	**10**	**410**	**1**	**2**	**0**	**4**	**1**	**297**	**2**	**731**
11:00 TO 11:15	0	0	0	1	111	0	2	0	0	0	79	1	
11:15 TO 11:30	0	0	3	0	129	0	3	0	0	0	79	1	
11:30 TO 11:45	1	0	2	1	89	0	2	0	0	1	93	0	
11:45 TO 12:00	0	0	0	0	73	0	1	0	2	0	84	0	
TOTAL	**1**	**0**	**5**	**2**	**402**	**0**	**8**	**0**	**2**	**1**	**335**	**2**	**758**
TOTAL P1	**10**	**5**	**23**	**27**	**2743**	**11**	**26**	**3**	**22**	**12**	**4138**	**6**	**7026**

DATE:
02 September 2016



COUNTERS	DIRECTION
MABINA	2
MABINA	4
MABINA	5
MABINA	6
MATHEBULA	1
MATHEBULA	7
MATHEBULA	8
MATHEBULA	9
BALOYI	3
BALOYI	10
BALOYI	11
BALOYI	12

TRAFFIC COUNTS

TIME	MOVEMENT												
	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
12:00 TO 12:15	0	0	0	0	72	0	1	0	2	3	73	0	
12:15 TO 12:30	1	0	0	0	91	0	1	0	1	3	75	0	
12:30 TO 12:45	0	1	1	0	76	1	0	1	0	0	90	0	
12:45 TO 13:00	0	0	2	1	113	0	0	0	0	0	98	0	
TOTAL	**1**	**1**	**3**	**1**	**352**	**1**	**2**	**1**	**3**	**6**	**336**	**0**	**707**
13:00 TO 13:15	0	0	1	0	109	0	0	1	0	1	93	0	
13:15 TO 13:30	0	0	2	4	88	3	0	0	0	3	123	0	
13:30 TO 13:45	0	0	1	1	115	0	0	0	0	0	130	0	
13:45 TO 14:00	0	0	3	2	93	1	2	0	1	4	65	0	
TOTAL	**0**	**0**	**7**	**7**	**405**	**4**	**2**	**1**	**1**	**8**	**411**	**0**	**846**
14:00 TO 14:15	0	0	3	1	118	1	0	1	0	2	84	0	
14:15 TO 14:30	0	0	2	2	109	0	1	0	1	1	127	0	
14:30 TO 14:45	1	0	0	0	112	0	0	0	0	0	139	0	
14:45 TO 15:00	1	0	0	0	119	3	1	0	0	2	177	1	
TOTAL	**2**	**0**	**5**	**3**	**458**	**4**	**2**	**1**	**1**	**5**	**527**	**1**	**1009**
15:00 TO 15:15	0	0	0	0	116	1	0	1	0	0	96	0	
15:15 TO 15:30	0	0	0	0	112	0	0	0	2	3	120	0	
15:30 TO 15:45	1	0	2	1	118		0	0	1	0	77	0	
15:45 TO 16:00	0	0	0	1	108	0	0	0	1	0	86	0	
TOTAL	**1**	**0**	**2**	**2**	**454**	**1**	**0**	**1**	**4**	**3**	**379**	**0**	**847**
16:00 TO 16:15	1	0	1	0	106	1	1	0	0	0	198	2	
16:15 TO 16:30	2	0	1	2	101	0	2	0	0	1	177	2	
16:30 TO 16:45	0	0	0	5	147	2	2	0	0	2	211	4	
16:45 TO 17:00	0	0	1	1	88	0	1	0	0	2	213	3	
TOTAL	**3**	**0**	**3**	**8**	**442**	**3**	**6**	**0**	**0**	**5**	**799**	**11**	**1280**
17:00 TO 17:15	0	0	0	2	85	3	0	0	1	0	198	0	
17:15 TO 17:30	0	0	1	0	81	1	0	0	0	0	177	0	
17:30 TO 17:45	0	0	0	1	78	0	0	0	0	0	164	0	
17:45 TO 18:00	0	0	0	0	71	1	0	0	1	0	159	0	
TOTAL	**0**	**0**	**1**	**3**	**315**	**5**	**0**	**0**	**2**	**0**	**698**	**0**	**1024**

TOTAL P2	**7**	**1**	**21**	**24**	**2426**	**18**	**12**	**4**	**11**	**27**	**3150**	**12**	**5713**

TOTAL P1	**10**	**5**	**23**	**27**	**2743**	**11**	**26**	**3**	**22**	**12**	**4138**	**6**	**7026**
TOTAL P2	**7**	**1**	**21**	**24**	**2426**	**18**	**12**	**4**	**11**	**27**	**3150**	**12**	**5713**
G-TOTAL	**17**	**6**	**44**	**51**	**5169**	**29**	**38**	**7**	**33**	**39**	**7288**	**18**	**12739**

Appendix 2: TRAFMAN accident count sample – Intersection of Pierneef Street and 20th Street

GEN-SAST		**NUMBER OF ACCIDENTS AND CASUALTIES PER MONTH**					**06/05/2019**				
		Excludes accidents on intersecting roads									
Authority:	PRETORIA(4046)					Section:	PIERNEEF STREET (1)				
Road:	PIERNEEF STREET (P0725)					Vehicle type	All				
Date:	01/01/2014 - 31/12/2018					Node:	70				
Year	**Month**	**Fatal accidents**	**Serious accidents**	**Slight accidents**	**Damage accidents**	**Total accidents**	**Fatal persons**	**Serious persons**	**Slight persons**	**No injury persons**	**Total persons**
2014	Feb	0	1	0	0	**1**	0	1	0	1	**2**
2014	Oct	0	0	0	1	**1**	0	0	0	2	**2**
2015	Jul	0	0	0	1	**1**	0	0	0	2	**2**
2015	Aug	0	0	0	1	**1**	0	0	0	2	**2**
2015	Nov	1	0	0	0	**1**	1	0	1	0	**2**
2016	May	0	0	0	1	**1**	0	0	0	2	**2**
2016	Aug	0	0	0	1	**1**	0	0	0	1	**1**
2016	Nov	0	0	0	1	**1**	0	0	0	2	**2**
2017	Feb	0	0	0	1	**1**	0	0	0	1	**1**
2017	Mrt	0	0	0	1	**1**	0	0	0	1	**1**
2017	Jun	0	0	0	2	**2**	0	0	0	3	**3**
2018	Feb	0	0	1	0	**1**	0	0	1	1	**2**
2018	Dec	0	0	0	1	**1**	0	0	0	0	**0**
	Total of all	**1**	**1**	**1**	**11**	**14**	**1**	**1**	**2**	**18**	**22**

Appendix 3: Intersection data analysis summary

(Sheet 1 of 5)

Intersection of		Road Class		Intersection Control Type	Intersection Geometry	12 hour traffic counts	Average Daily Traffic (ADT) (before 3% growth	Base year adjustm.	Average Daily Traffic (ADT)	Traffic counts - Date	Estimated Annual Traffic	Total accidents January 2014 to December 2018 (5 year period)					Accident Frequency (number /year)	Accident Rate (RMEV - Rate /million of entering vehicles)	Accident Severity Frequency (EAN) (no./ year)	Accident Severity Rate (RMEV - Rate /million of entering vehicles)
Street Name (1)	Street Name (2)	(1)	(2)					01-Jul-16				Fatal	Ser.	Slight	Dam.	Total				
Bothma	Bergen	5	5	All-way Control - Stop	Four-legged	1030	1236	-0,97	1201	20-Jun-17	360321	0	0	0	0	0	0	0,00	0	0,00
Bothma	Imatra	5	5	All-way Control - Stop	Four-legged	1864	2237	2,09	2380	29-May-14	713869	0	0	0	0	0	0	0,00	0	0,00
De Beer	19th	5	5	All-way Control - Stop	Four-legged	2879	3455	-0,55	3399	17-Jan-17	1019788	0	0	0	0	0	0	0,00	0	0,00
Ireland	Kort	5	5	All-way Control - Stop	Three-legged	2837	3404	2,04	3616	19-Jun-14	1084660	0	0	0	0	0	0	0,00	0	0,00
Mulders Mile	De Uitsig	4A	5	All-way Control - Stop	Three-legged	3103	3724	1,10	3846	28-May-15	1153858	0	0	1	2	3	0,6	0,52	1	0,87
Hertzog	Beves	4A	4B	All-way Control - Stop	Three-legged	3591	4309	1,39	4489	11-Feb-15	1346834	0	0	0	0	0	0	0,00	0	0,00
Bruarfoss	Fjord	5	4A	All-way Control - Stop	Multi-legged	4186	5023	-0,80	4906	19-Apr-17	1471743	0	0	0	1	1	0,2	0,14	0,2	0,14
Kestrel	Kraanvoel	4A	5	All-way Control - Stop	Four-legged	4852	5822	-0,05	5813	21-Jul-16	1743893	0	0	1	2	3	0,6	0,34	1	0,57
Mulders Mile	Swart	4A	5	All-way Control - Stop	Four-legged	4857	5828	1,10	6021	26-May-15	1806380	0	0	0	3	3	0,6	0,33	0,6	0,33
Masopha	Makaza	4A	4A	All-way Control - Stop	Four-legged	5154	6185	1,35	6436	25-Feb-15	1930860	0	0	1	3	4	0,8	0,41	1,2	0,62
Lochner	Erasmus	4A	4B	All-way Control - Stop	Four-legged	6216	7459	-2,05	7021	19-Jul-18	2106231	0	0	1	4	5	1	0,47	1,4	0,66
Galway	Pine	5	5	All-way Control - Stop	Four-legged	7390	8868	-1,07	8593	25-Jul-17	2577897	0	0	2	4	6	1,2	0,47	2	0,78
Hans Coverdale	John Sydney	4B	5	All-way Control - Stop	Three-legged	7871	9445	1,12	9762	21-May-15	2928511	0	2	0	21	23	4,6	1,57	7,4	2,53
Mopani	Blackwood	5	5	All-way Control - Stop	Four-legged	8124	9749	1,14	10082	13-May-15	3024602	0	0	2	17	19	3,8	1,26	4,6	1,52
Bosloerie	Koekoek	4A	4A	All-way Control - Stop	Four-legged	8626	10351	0,22	10418	12-Apr-16	3125544	0	0	1	7	8	1,6	0,51	2	0,64
Panorama	Alice	4A	5	All-way Control - Stop	Four-legged	10235	12282	0,22	12361	13-Apr-16	3708248	0	0	1	12	13	2,6	0,70	3	0,81
Panorama	Kestrel	4A	4A	All-way Control - Stop	Three-legged	12772	15326	-1,08	14843	01-Aug-17	4452807	0	0	5	13	18	3,6	0,81	5,6	1,26
Theuns Van Niek	Underberg	4A	5A	All-way Control - Stop	Four-legged	13969	16763	-0,65	16444	23-Feb-17	4933242	0	0	0	11	11	2,2	0,45	2,2	0,45
Heuwel	Suid	4A	4A	All-way Control - Stop	Four-legged	22509	27011	-2,64	24984	19-Feb-19	7495309	0	2	7	38	47	9,4	1,25	15	2,00
De Villebois Mar	Atterbury	3	2	All-way Control - Stop	Four-legged	29792	35750	-1,62	34077	13-Feb-18	10223068	0	1	24	179	204	40,8	3,99	51,8	5,07
Casper	Eloff	5	5	Priority Control - Stop	Four-legged	592	710	-2,05	669	18-Jul-18	200610	0	1	2	4	7	1,4	6,98	3,6	17,95
Lochner	Mimosa	4A	3	Priority Control - Stop	Three-legged	666	799	1,60	838	24-Nov-14	251392	0	0	0	0	0	0	0,00	0	0,00

(Sheet 2 of 5)

Intersection of		Road Class		Intersection Control Type	Intersection Geometry	12 hour traffic counts	Average Daily Traffic (ADT) (before 3% growth	Base year adjustm	Average Daily Traffic (ADT)	Traffic counts - Date	Estimated Annual Traffic	Total accidents January 2014 to December 2018 (5 year period)					Accident Frequency (number /year)	Accident Rate (RMEV - Rate /million of entering vehicles)	Accident Severity Frequency (EAN) (no./ year)	Accident Severity Rate (RMEV - Rate /million of entering vehicles)
Street Name (1)	Street Name (2)	(1)	(2)					01-Jul-16				Fatal	Ser.	Slight	Dam.	Total				
Bruarfoss	Hammerfest	5	5	Priority Control - Stop	Four-legged	932	1118	-0,67	1097	02-Mar-17	328955	0	1	3	3	7	1,4	4,26	4	12,16
Strachan	Gideon Scheeper	5	5	Priority Control - Stop	Three-legged	1008	1210	0,47	1226	13-Jan-16	367910	0	0	0	0	0	0	0,00	0	0,00
Godiva	Bodo	5	5	Priority Control - Stop	Three-legged	1125	1350	2,44	1451	23-Jan-14	435268	0	0	0	1	1	0,2	0,46	0,2	0,46
Leonie	Toermalien	4A	5	Priority Control - Stop	Three-legged	2041	2449	2,04	2602	17-Jun-14	780454	0	0	0	2	2	0,4	0,51	0,4	0,51
Citron	Goven Mbeki	3	3	Priority Control - Stop	Four-legged	2494	2993	0,43	3031	27-Jan-16	909255	0	0	5	9	14	2,8	3,08	4,8	5,28
Berg	Burger	4B	5	Priority Control - Stop	Four-legged	2646	3175	-0,61	3118	09-Feb-17	935512	0	0	1	2	3	0,6	0,64	1	1,07
Grobler	Irvine	5	5	Priority Control - Stop	Four-legged	2830	3396	-0,36	3360	09-Nov-16	1008049	0	1	2	1	4	0,8	0,79	3	2,98
Murray	Hay	4B	5	Priority Control - Stop	Four-legged	2958	3550	-0,93	3453	07-Jun-17	1035875	0	0	1	10	11	2,2	2,12	2,6	2,51
Swemmer	13th	4B	4B	Priority Control - Stop	Four-legged	3196	3835	-1,28	3693	11-Oct-17	1107859	0	1	2	5	8	1,6	1,44	3,8	3,43
Malan	Union	5	5	Priority Control - Stop	Four-legged	3105	3726	2,34	3993	27-Feb-14	1197939	0	0	0	4	4	0,8	0,67	0,8	0,67
Jochem	View	4B	4B	Priority Control - Stop	Three-legged	3934	4721	-0,73	4621	23-Mar-17	1386171	0	0	0	4	4	0,8	0,58	0,8	0,58
Brown	19th	4A	4A	Priority Control - Stop	Three-legged	3912	4694	1,33	4882	05-Mar-15	1464616	0	0	0	1	1	0,2	0,14	0,2	0,14
President Burgers	Christoffel	5	5	Priority Control - Stop	Four-legged	4934	5921	1,12	6120	20-May-15	1835909	0	3	5	30	38	7,6	4,14	13,8	7,52
Meyer	23rd	4A	5	Priority Control - Stop	Four-legged	5393	6472	-0,80	6320	20-Apr-17	1895955	0	0	1	4	5	1	0,53	1,4	0,74
Masopha	Marivate	4A	4A	Priority Control - Stop	Three-legged	6163	7396	1,08	7636	02-Jun-15	2290799	0	0	1	8	9	1,8	0,79	2,2	0,96
Louisa	Aletta	4B	4B	Priority Control - Stop	Three-legged	6535	7842	-0,72	7676	22-Mar-17	2302836	0	0	4	8	12	2,4	1,04	4	1,74
Murray	Roper	4B	4B	Priority Control - Stop	Three-legged	7086	8503	-1,95	8027	12-Jun-18	2408227	0	0	0	6	6	1,2	0,50	1,2	0,50
Willem Botha	Friederiche	4A	5	Priority Control - Stop	Four-legged	6598	7918	2,36	8490	20-Feb-14	2547017	0	0	2	8	10	2	0,79	2,8	1,10
Bosloerie	Badenhorst	4A	5	Priority Control - Yield	Three-legged	7709	9251	-0,25	9184	29-Sep-16	2755086	0	0	2	3	5	1	0,36	1,8	0,65
Campbell	Visby / Tyman	4A	5	Priority Control - Stop	Four-legged	7376	8851	2,12	9423	20-May-14	2826898	0	0	0	2	2	0,4	0,14	0,4	0,14
Moot	Welthagen	3A	5	Priority Control - Stop	Four-legged	8979	10775	-1,93	10176	07-Jun-18	3052812	0	3	8	26	37	7,4	2,42	14,8	4,85
Lynette	Magdelena	4A	5	Priority Control - Stop	Four-legged	8633	10360	2,36	11110	19-Feb-14	3332855	0	0	1	2	3	0,6	0,18	1	0,30

(Sheet 3 of 5)

Intersection of		Road Class		Intersection Control Type	Intersection Geometry	12 hour traffic counts	Average Daily Traffic (ADT) (before 3% growth	Base year adjustm 01-Jul-16	Average Daily Traffic (ADT)	Traffic counts - Date	Estimated Annual Traffic	Total accidents January 2014 to December 2018 (5 year period)					Accident Frequency (number /year)	Accident Rate (RMEV - Rate /million of entering vehicles)	Accident Severity Frequency (EAN) (no./ year)	Accident Severity Rate (RMEV - Rate /million of entering vehicles)
Street Name (1)	Street Name (2)	(1)	(2)									Fatal	Ser.	Slight	Dam.	Total				
Panorama	Strandloper	4A	5	Priority Control - Stop	Three-legged	9703	11644	1,82	12289	04-Sep-14	3686651	0	0	2	16	18	3,6	0,98	4,4	1,19
Johannes Ramokh	Cowie	3A	3A	Priority Control - CBD	Four-legged	10643	12772	-0,36	12638	08-Nov-16	3791355	0	12	18	78	108	21,6	5,70	45,6	12,03
Pierneef	20th	4B	5	Priority Control - Stop	Four-legged	12739	15287	-0,17	15209	02-Sep-16	4562702	1	1	1	11	14	2,8	0,61	6,8	1,49
Frates	Terblanche	3	3	Priority Control - Stop	Four-legged	12831	15397	0,24	15505	06-Apr-16	4651443	0	2	10	21	33	6,6	1,42	13,4	2,88
Pierneef	21st	4B	5	Priority Control - Stop	Four-legged	12932	15518	0,39	15699	09-Feb-16	4709747	0	0	0	4	4	0,8	0,17	0,8	0,17
Rooihuiskraal	Kolgans	3	5	Priority Control - Stop	Four-legged	12385	14862	2,39	15948	11-Feb-14	4784450	0	0	12	10	22	4,4	0,92	9,2	1,92
Saxby	Cradock E & W	4A	5	Priority Control - Stop	Four-legged	15257	18308	-0,84	17862	02-May-17	5358517	0	1	12	18	31	6,2	1,16	12,4	2,31
Francis Baard	Farenden	3A	5	Priority Control - Stop	Four-legged	19521	23425	1,18	24255	28-Apr-15	7276589	2	2	6	19	29	5,8	0,80	15,4	2,12
Migmatite	Edward	4B	5	Traffic circle - 17m Ø	Three-legged	7037	8444	-0,63	8289	16-Feb-17	2486571	0	1	0	17	18	3,6	1,45	5	2,01
Braam Pretorius	Visvanger	4A	4A	Traffic circle - 24m Ø	Four-legged	7883	9460	0,10	9487	26-May-16	2846166	0	1	2	10	13	2,6	0,91	4,8	1,69
Sekhu	Moroe	4A	4A	Traffic circle - 25m Ø	Four-legged	7739	9287	1,43	9687	27-Jan-15	2906104	0	2	1	17	20	4	1,38	7,2	2,48
Braam Pretorius	Dr Van Der Merw	4A	4A	Traffic circle - 23m Ø	Four-legged	9224	11069	0,12	11107	19-May-16	3332224	0	0	4	17	21	4,2	1,26	5,8	1,74
Lynette	Anna Wilson	4A	4A	Traffic circle - 19m Ø	Four-legged	10988	13186	1,19	13659	22-Apr-15	4097845	0	0	1	8	9	1,8	0,44	2,2	0,54
Jakaranda	Edward	5	5	Traffic circle - 21m Ø	Four-legged	12659	15191	-3,07	13875	25-Jul-19	4162422	0	0	8	18	26	5,2	1,25	8,4	2,02
Lois	Ingersol	4A	4A	Traffic circle - 31m Ø	Three-legged	13042	15650	0,39	15830	11-Feb-16	4749039	0	0	0	4	4	0,8	0,17	0,8	0,17
Maunde	Makaza	3	4A	Traffic circle - 48m Ø	Four-legged	13582	16298	0,31	16450	09-Mar-16	4934869	1	1	3	17	22	4,4	0,89	9,2	1,86
Braam Pretorius	Dr Swanepoel	4A	2	Traffic circle - 18m Ø	Four-legged	14321	17185	0,35	17366	23-Feb-16	5209701	0	1	6	30	37	7,4	1,42	11,2	2,15
Rooihuiskraal	Waterberg	3	3	Traffic Signals	Three-legged	8607	10328	1,79	10889	17-Sep-14	3266786	0	0	1	3	4	1,2	0,38	1,2	0,37
Tsamaya	Solomon Mahlang	3	2	Traffic Signals	Four-legged	11253	13504	0,45	13683	20-Jan-16	4104910	0	1	2	17	20	4	0,97	6,2	1,51
Van Ryneveld	Van der Spuy	3	5	Traffic Signals	Four-legged	13744	16493	1,87	17429	19-Aug-14	5228799	0	1	2	10	13	2,6	0,50	4,8	0,92
Glenwood	Oberon	4A	3A	Traffic signals	Three-legged	15726	18871	-1,68	17957	06-Mar-18	5387177	0	0	7	27	34	6,8	1,26	9,6	1,78
Moot	Hendricks	3A	4B	Traffic Signals	Four-legged	18182	21818	-0,95	21212	14-Jun-17	6363629	0	2	13	54	69	13,8	2,17	21,8	3,43

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Intersection of		Road Class		Intersection Control Type	Intersection Geometry	12 hour traffic counts	Average Daily Traffic (ADT) (before 3% growth	Base year adjustm 01-Jul-16	Average Daily Traffic (ADT)	Traffic counts - Date	Estimated Annual Traffic	Total accidents January 2014 to December 2018 (5 year period)					Accident Frequency (number /year)	Accident Rate (RMEV - Rate /million of entering vehicles)	Accident Severity Frequency (EAN) (no./ year)	Accident Severity Rate (RMEV - Rate /million of entering vehicles)
Street Name (1)	Street Name (2)	(1)	(2)									Fatal	Ser.	Slight	Dam.	Total				
Wierda	Ashwood	2	4A	Traffic Signals	Four-legged	17036	20443	2,41	21950	04-Feb-14	6584910	0	3	9	42	54	10,8	1,64	18,6	2,82
Paul Kruger	Fred Nicholson	3A	4A	Traffic Signals	Four-legged	22019	26423	-2,22	24743	20-Sep-18	7422955	2	12	36	160	210	42	5,66	77,6	10,45
Garstfontein	Dely	3A	3A	Traffic signals	Three-legged	22599	27119	-0,68	26575	08-Mar-17	7972584	0	1	4	66	71	14,2	1,78	17,2	2,16
Hendrik Verwoer	South	3	4A	Traffic signals	Four-legged	22956	27547	0,07	27601	07-Jun-16	8280238	0	0	6	51	57	11,4	1,38	13,8	1,67
Tsamaya	Sibande	3	4A	Traffic Signals	Four-legged	23211	27853	1,42	29051	28-Jan-15	8715353	0	0	4	28	32	6,4	0,73	8	0,92
Hendrik Verwoer	Migmatite	3	4B	Traffic signals	Three-legged	25186	30223	-0,61	29685	08-Feb-17	8905409	0	0	3	35	38	7,6	0,85	8,8	0,99
Saxby	Ruimte	3	2	Traffic Signals	Four-legged	26382	31658	-1,64	30159	20-Feb-18	9047802	0	1	15	74	90	18	1,99	25,4	2,81
WF Nkomo	Rod / Strachan	2	4A	Traffic Signals	Four-legged	27926	33511	-2,08	31511	31-Jul-18	9453261	0	5	18	118	141	28,2	2,98	42,4	4,49
WF Nkomo	Rebecca	3	4A	Traffic Signals	Four-legged	29627	35552	-0,32	35214	27-Oct-16	10564284	0	6	22	179	207	41,4	3,92	58,6	5,55
Quagga	Rod	3A	4A	Traffic Signals	Three-legged	31710	38052	-1,68	36206	07-Mar-18	10861857	1	5	7	47	60	12	1,10	24	2,21
Pierneef	Frates	4B	3A	Traffic Signals	Four-legged	29906	35887	0,32	36223	08-Mar-16	10866894	0	1	5	37	43	8,6	0,79	12	1,10
Panorama	Rooihuiskraal	4A	3	Traffic Signals	Four-legged	31401	37681	2,06	40044	11-Jun-14	12013208	0	3	11	124	138	27,6	2,30	36,2	3,01
Quagga	Maunde	2	3	Traffic Signals	Three-legged	33459	40151	0,06	40222	09-Jun-16	12066719	1	6	16	131	154	30,8	2,55	47,8	3,96
Old Johannesburg	Saxby / Lyttellton	2	3	Traffic Signals	Four-legged	36212	43454	-2,54	40308	15-Jan-19	12092520	0	2	8	85	95	19	1,57	25	2,07
Lynnwood	Atterbury	3A	3	Traffic signals	Four-legged	37050	44460	-2,58	41194	29-Jan-19	12358340	0	3	20	151	174	34,8	2,82	47	3,80
Garstfontein	De Villebos Mare	2	3	Traffic signals	Four-legged	32419	38903	2,06	41346	10-Jun-14	12403673	0	2	36	155	193	38,6	3,11	55,8	4,50
Hendrik Verwoer	Galway	3	5	Traffic signals	Four-legged	38366	46039	-0,70	45091	15-Mar-17	13527272	0	0	9	109	118	23,6	1,74	27,2	2,01
Trans Oranje	WF Nkomo	3	3	Traffic Signals	Four-legged	39701	47641	-0,32	47192	26-Oct-16	14157579	2	16	48	399	465	93	6,57	139	9,82
George Storrar	Leyds	3	4A	Traffic signals	Three-legged	40056	48067	-0,59	47238	01-Feb-17	14171259	0	1	14	48	63	12,6	0,89	19,6	1,38
Lynnwood	Simon Vermooter	2	3	Traffic signals	Four-legged	40470	48564	-0,65	47641	23-Feb-17	14292240	0	2	25	229	256	51,2	3,58	64	4,48
Bremer	Van der Hoff	3	3A	Traffic signals	Four-legged	41091	49309	-0,30	48876	18-Oct-16	14662757	1	9	40	272	322	64,4	4,39	95,2	6,49
George Storrar	Florence Ribeiro	3A	3A	Traffic signals	Four-legged	41631	49957	-0,55	49151	18-Jan-17	14745180	0	2	5	34	41	8,2	0,56	13	0,88
Hendrik Verwoer	Old Johannesburg	3	2	Traffic signals	Four-legged	45052	54062	-2,20	50659	12-Sep-18	15197589	0	2	42	219	263	52,6	3,46	72,2	4,75

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Intersection of		Road Class		Intersection Control Type	Intersection Geometry	12 hour traffic counts	Average Daily Traffic (ADT) (before 3% growth	Base year adjustm 01-Jul-16	Average Daily Traffic (ADT)	Traffic counts - Date	Estimated Annual Traffic	Total accidents January 2014 to December 2018 (5 year period)					Accident Frequency (number /year)	Accident Rate (RMEV - Rate /million of entering vehicles)	Accident Severity Frequency (EAN) (no./ year)	Accident Severity Rate (RMEV - Rate /million of entering vehicles)
Street Name (1)	Street Name (2)	(1)	(2)									Fatal	Ser.	Slight	Dam.	Total				
John Vorster	Olievenhoutbosc	2	3	Traffic signals	Four-legged	44100	52920	-0,15	52693	23-Aug-16	15808005	0	4	5	50	59	11,8	0,75	19,4	1,23
Atterbury	Jacqueline	2	3A	Traffic signals	Four-legged	48400	58080	-2,58	53810	30-Jan-19	16142920	0	1	10	63	74	14,8	0,92	20,2	1,25
Brooklyn / Duxbu	Lynnwood	3A	3A	Traffic signals	Four-legged	45753	54904	-0,34	54359	01-Nov-16	16307827	0	3	23	151	177	35,4	2,17	48,8	2,99
Justice Mahomed	Jan Shoba	3A	3A	Traffic signals	Four-legged	45011	54013	0,37	54611	16-Feb-16	16383412	0	2	14	178	194	38,8	2,37	47,2	2,88
John Voster	Hendrik Verwoer	3	3	Traffic signals	Four-legged	46507	55808	-0,62	54787	14-Feb-17	16436220	0	7	31	171	209	41,8	2,54	64	3,89
Sefako Makgatho	Dr Swanepoel	2	2	Traffic Signals	Four-legged	48210	57852	-0,15	57595	25-Aug-16	17278469	2	11	36	289	338	67,6	3,91	101,8	5,89
Solomon Mahlang	Boeing	2	3	Traffic Signals	Four-legged	47762	57314	0,83	58738	02-Sep-15	17621451	0	5	23	128	156	31,2	1,77	47,4	2,69
Lynnwood	Jan Shoba	3A	3A	Traffic signals	Four-legged	47785	57342	1,94	60726	24-Jul-14	18217752	0	5	34	175	214	42,8	2,35	63,4	3,48
Lynnwood	January Maselela	2	3	Traffic signals	Three-legged	54491	65389	-1,56	62434	23-Jan-18	18730309	2	4	33	339	378	75,6	4,04	98,8	5,27
Lynnwood	Solomon Mahlang	2	2	Traffic signals	Four-legged	56793	68152	-2,29	63685	16-Oct-18	19105553	1	9	32	229	271	54,2	2,84	81,8	4,28
Solomon Mahlang	Atterbury	2	2	Traffic Signals	Four-legged	58507	70208	-2,34	65522	01-Nov-18	19656668	0	3	43	247	293	58,6	2,98	80	4,07
Atterbury	Lois	2	3A	Traffic signals	Four-legged	65795	78954	-2,56	73190	23-Jan-19	21957143	0	8	60	602	670	134	6,10	169,2	7,71
Atterbury	January Masilela	2	3	Traffic signals	Four-legged	61570	73884	0,18	74280	26-Apr-16	22283987	0	6	34	263	303	60,6	2,72	82,6	3,71
Atterbury	Justice Mahomed	3	3A	Traffic signals	Four-legged	63937	76724	0,43	77706	26-Jan-16	23311838	0	2	16	151	169	33,8	1,45	43	1,84
Kgosi Mampuru	Bloed	3A	3A	Traffic signals - CBD	Four-legged	11008	13210	1,39	13763	10-Feb-15	4128976	0	7	15	147	169	33,8	8,19	49,6	12,01
Robert Sobukwe	Nelson Mandela	3A	3A	Traffic Signals - CBD	Three-legged	14416	17299	-2,12	16247	15-Aug-18	4874052	0	1	2	49	52	10,4	2,13	12,6	2,59
Bosman	Jeff Masemola	3A	3A	Traffic signals - CBD	Four-legged	20618	24742	-0,82	24152	25-Apr-17	7245498	0	8	18	307	333	66,6	9,19	85	11,73
Lilian Ngoyi	Boom	3A	3A	Traffic signals - CBD	Three-legged	19601	23521	2,02	24968	25-Jun-14	7490337	0	4	10	110	124	24,8	3,31	34,4	4,59
Sophie de Bruyn	Visagie	3A	3A	Traffic signals - CBD	Four-legged	26759	32111	1,31	33378	11-Mar-15	10013453	1	7	34	147	189	37,8	3,77	63,4	6,33
Madiba	Thabo Sehume	3A	3A	Traffic signals - CBD	Four-legged	27177	32612	0,88	33477	13-Aug-15	10043014	0	4	32	330	366	73,2	7,29	91,6	9,12
Thabo Sehume	Johannes Ramokh	3A	3A	Traffic signals - CBD	Four-legged	28623	34348	0,88	35258	13-Aug-15	10577370	1	9	16	219	245	49	4,63	70,2	6,64
Nelson Mandela	Madiba	3A	3A	Traffic signals - CBD	Four-legged	28741	34489	1,71	36277	16-Oct-14	10883053	0	3	17	93	113	22,6	2,08	33,6	3,09
Sophie De Bruyn	Jeff Masemola	3A	3A	Traffic signals - CBD	Four-legged	34754	41705	-0,82	40710	25-Apr-17	12213116	1	3	9	90	103	20,6	1,69	30,6	2,51

Appendix 4: Journal publications and conference presentations

Southern African Transport Conference (SATC)

Sarjoo, A. R. and Allopi, D. 2020. The development of road safety assessment screening procedures for the City of Tshwane Metropolitan Municipality. 39th Southern African Transport Conference (Accepted for SATC 2021).

Institute of Municipal Engineering of Southern Africa (IMESA)

Sarjoo, A. R. and Allopi, D. 2020. Non-motorised transport and intersection crash prediction models. Institute of Municipal Engineering of Southern Africa, July 2020, ISSN 0257 1978.

Appendix 5: Editing certificate

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EDITING CERTIFICATE

Re: **ARVIN SARJOO**
For editing DUT Master's dissertation: **THE DEVELOPMENT OF ROAD SAFETY ASSESSMENT SCREENING PROCEDURES FOR THE CITY OF TSHWANE METROPOLITAN MUNICIPALITY**

I confirm that I have edited this dissertation and the references for clarity, language and layout. I returned the document to the author with track changes so correct implementation of the changes and clarifications requested in the text and references is the responsibility of the author. I am a freelance editor specialising in proofreading and editing academic documents. My original tertiary degree which I obtained at the University of Cape Town was a B.A. with English as a major and I went on to complete an H.D.E. (P.G.) Sec. with English as my teaching subject. I obtained a distinction for my M.Tech. dissertation in the Department of Homoeopathy at Technikon Natal in 1999 (now the Durban University of Technology). I was a part-time lecturer in the Department of Homoeopathy at the Durban University of Technology for 13 years.

Dr Richard Steele
9 JUNE 2020
per email