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

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## ABSTRACT

In the global context, South Africa, as characteristic of many developing countries with limited resources, faces the challenge to proactively manage, reduce and eliminate the high incidence of road crashes, injuries and fatalities. Due to an absence of practical 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 for the development of procedures with measurable benefits in promoting a safer road environment. The research scope is limited to road safety engineering and the road network within CTMM boundaries. However, aspects of the study can be generalised to other municipalities. The research used data from the CTMM accident database, traffic count database including road classification, and design information from the ARCGIS system, to determine a linear regression model for accident rate prediction. The model can be used to establish screening procedures for effective prioritisation of scarce funding as well as a safety comparison of selected intersection control types. Intersection controls and traffic safety measures such as traffic signs, traffic circles and traffic signals were assessed for effectiveness in reducing the Rate of accidents per Million of Entering Vehicles (RMEV's). The results show a relationship between Average Daily Traffic (ADT) and Accident Frequency. The linear regression equation allows for the prediction of crash rates and the prioritization of road safety projects. The findings in addition illustrate approximately a twofold increase in accident rates on higher order roads, typically traffic signal-controlled intersections. Factors such as a greater number of intersection conflict points, greater pedestrian volumes and increased intersection saturation or volume/capacity levels contributed to higher accident rates.

## 1. INTRODUCTION

The City of Tshwane Metropolitan Municipality's (CTMM) response to road safety challenges is partially addressed on a strategic level in its Comprehensive Integrated Transport Plan (CITP, 2015), with its goals described as to *"Improve the safety and security of the transport system"* (City of Tshwane 2015:15-5). However, on an operational or functional level a need exists for the development of practical, measurable and *a results* focused Road Safety Assessment and Audit procedure within the CTMM. Intersections constitute a relatively small portion of the road network but intersection related crashes contribute to 20% of all fatal crashes (FHWA 2013:6-4). In developing countries there is a need 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 cycle.

The research problem can be defined by the absence of routine Road Safety Assessment and Audit procedures within the responsible CTMM departments. This has a 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. The Tshwane Road Safety Management Strategy involves various role players including the CTMM Traffic Engineering & Operations section, the Tshwane Metro Police Department, the Emergency Services Department, the Gauteng Department of Community Safety, the South African National Roads Agency, the Road Traffic Management Corporation, the South African Police Service and the South African National Taxi Council.

## 2. LITERATURE REVIEW

The South African road fatality rate as a middle-income country is reported to be 23.5 fatalities per 100 000 population, notably higher than the global average for middle-income countries at 18.4 fatalities per 100 000 population (Road Traffic Management Corporation 2016:12). The challenges experienced by road authorities for the implementation of Road Safety Assessments or Audits include the lack of capacity, funding, time constraints and lack of support and training (Grosskopf et al., 2010:3).The concept of nominal and substantive safety describes shortcomings in the application of design standards where the design engineer assumes that meeting minimum specifications equals safety. Road safety issues however usually only arise after newly built roads are opened to traffic operations where the disparity between design standards, nominal safety and substantive safety show up shortcomings in the reliance of standards as a means to ensure safe roads (Milton, 2012:6).

### 2.1 Road Safety Management Process

The Highway Safety Manual (HSM, 2014) outlines the Roadway Safety Management Process as per Figure 1 with the relationships for safety performance based on exposure and roadway conditions. This study focuses on the network screening stage in which 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, namely: establish the focus of network screening, identify the network and reference population, select the performance measures, select screening method, and evaluate the results (Kolody et al., 2014:2-2).


**Figure 1: The Roadway Safety Management Process (Kolody et al., 2014)**

## 2.2 The Causes and Factors Affecting of Crash Rates

Studies into the causes of fatal crashes indicate that human factors account for 73.6%, vehicle factors 14.1% and roads and the environment 12.3% of all fatal crashes (Department of Transport, 2016:27). While transportation engineering typically focuses on the 12.3% attributed to “road and environment”, greater reductions in fatalities may be achieved by directing scarce resources and funds towards a “safe systems” approach that focuses on the 73.6% “human factors” influence on fatalities. The Safe Systems Approach is internationally accepted as best practice in road safety strategy that requires a more forgiving approach to accidents that acknowledges that people make mistakes, and the road transport system must absorb these mistakes to prevent death or serious injury (Department of Transport, 2016:13).

The Safe System principles are echoed by the International Transport Forum (2018:56), which states 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.

### *2.2.1 The Relationship Between Road Safety and Traffic Congestion*

The 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 & 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).

The volume-to-capacity ratio (V/C) is described by Zhou and Sisiopiku (1997: 52), as more representative of accident exposure as it includes both road geometric and operational characteristics, as shown in Figure 2 below.

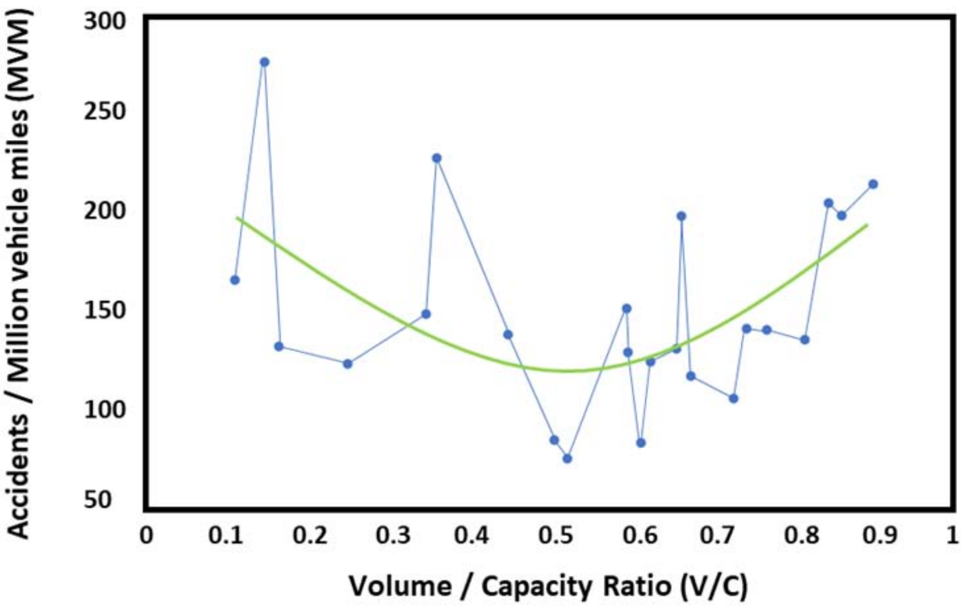
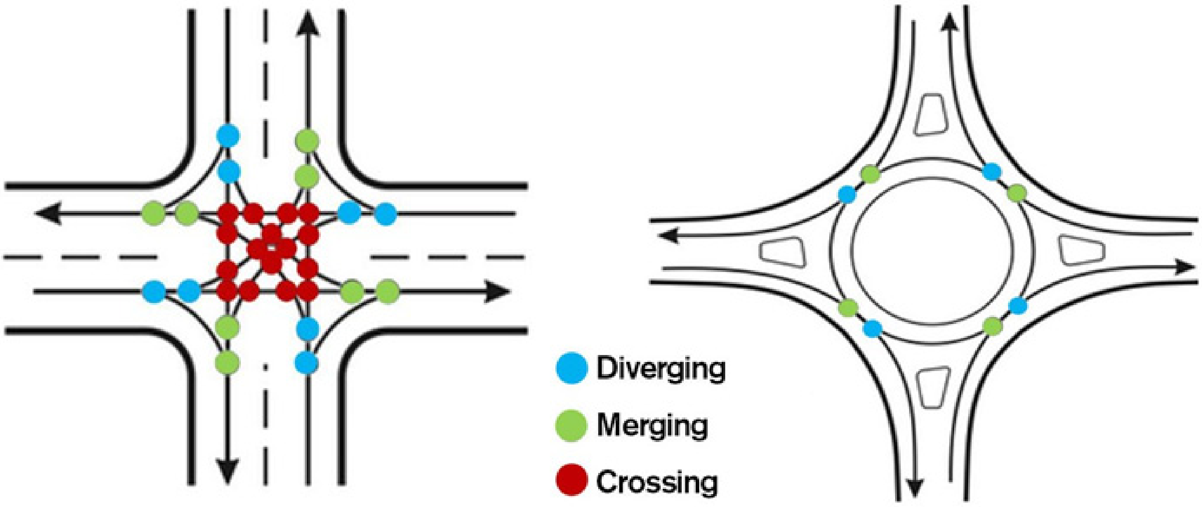



**Figure 2: Accident rate versus v/c ratio for weekdays, (Zhou & Sisiopiku, 1997:50)**

A U-shaped trend is clear between accidents per million vehicle miles and V/C. The function is further described by time periods with low V/C characteristics (for example at night-time) as displaying high accident rates. Single-vehicle accident rates indicated a decreasing trend with increasing V/C ratios, where factors other than capacity issues such as alcohol, fatigue and lighting conditions more often occur during off-peak traffic periods (i.e. at low V/C). For low V/C, as the V/C rate increases the accident rate decreases, reaches a minimum at approximately 50%-60% V/C capacity, possibly due to uniform, predictable traffic flow. For higher V/C, accident rates increase again as the V/C approaches congested traffic flow conditions. However, the study also found that for higher V/C ratios resulted in *decreasing severity* rates (in terms of injury and fatalities), which could likely be explained by typically lower average speeds during V/C levels approaching capacity or congestion.

### *2.2.2 Intersection Conflict Points*

Intersection conflicts occur when traffic flows in different directions interfere with each other. Figure 3.shows a comparison between a typical four-legged, traffic signal-controlled intersection and a single lane roundabout. A conflict point is a location where the paths of two vehicles, or a vehicle and a pedestrian diverge, merge, or cross each other. The figure indicates 32 vehicle-to-vehicle conflict points for four-leg intersections and 8 vehicle to vehicle conflict points for roundabouts (a 75 percent decrease).




Source: Arizona State University (2019)

**Figure 3: Typical intersection conflict points**

The most severe crashes at intersections occur when there is driver error at a traffic control device designed to separate conflicts by space and time, for example, a crash due to a vehicle running a red light, or vehicle-pedestrian collisions. Roundabouts have the ability to reduce conflicts through physical, geometric features, by reducing the number and complexity of driver decisions. This is typically more effective than the reliance of driver obedience to other more complex traffic control devices such as traffic signals (FHWA 2000: 26).

### *2.2.3 The Effect of Economic Downturn and Recession on Crashes*

An important factor in the analysis of crash statistics especially in the current economic conditions is the correlation of economic growth and crashes. Research conducted by the International Transport Forum (2015) described several factors that contribute to a reduction in crashes during periods of low economic growth. These factors include a reduction in traffic or exposure rates, i.e., due to decreased kilometres driven of particularly 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 a reduction in alcohol consumption, which greatly reduces the risk of speeding and drink-driving related crashes respectively.

### 2.3 The Economic Cost of Crashes and Prioritisation of Funding

The total cost of road traffic crashes in South Africa was estimated to amount to R 142.9 billion for 2015, which represented about 3.4 per cent of the Gross National Product (GDP) (Labuschagne et al., 2017:474). Due to competition for funding, road safety projects should be ranked via a cost-benefit analysis. As an example, speed enforcement has a Benefit/Cost (B/C) ratio of between 2.9 to 3.6, and therefore should an amount of R 1.0 million be invested in effective speed enforcement, an improvement in road safety (measured in terms of crash cost savings) of up to R 3.6 million could be expected. However, greater returns may be realised by investing R1.0 million rand in an effective drinking and driving campaign with a higher B/C ratio of 4.7 to 20 which could result in a cost saving of between R 4.7 and R 20 million and associated life savings (Labuschagne et al. 2017:483).

## 3. RESEARCH METHODOLOGY

The scope of the research was governed by the large geographical scale of the City of Tshwane Metropolitan Municipality (CTMM) which covers a land area of 6,368 square kilometres making it the third largest land area city in the world after New York and Tokyo. The research objectives were therefore to focus on a top-down view of road safety that addressed screening methods to identify the highest priority areas for more detailed road safety studies.

The primary sources of data used were: accident data from the Traffic Authority Management Information System (TRAFMAN), traffic count data from the CTMM traffic database, and road classification data, intersection geometry and intersection control type from the CTMM Geographic Information System (ARCGIS). A five-year accident record was used, between January 2014 and December 2018, with a sample size of one hundred and twelve (112) intersections. The intersections were further categorized 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 specifically located in the Pretoria Central Business District (CBD).The high pedestrian volumes present in the Pretoria CBD significantly increases the number of traffic conflict points and therefore differentiates these intersections from other traffic signal-controlled intersections.

As per the recommendations of the Highway Safety Manual (Garber & 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 Equivalent Accident Number (EAN) takes into account the severity of an accident by the application of weights dependent on the cost of the accident. Table 1 demonstrates the weightings used, where a fatal accident is weighted 12 times that of a damage only or non-injury accident (Aucamp, 2014:38).

**Table 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:

$$Crash\ Frequency = \frac{Crashes}{Year} = \frac{\sum Crashes\ over\ 5 years}{5\ years} \tag{1}$$

Crash rates are determined on the basis of exposure data, such as traffic volume 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 Kilometers (RMVK) for road segments (Garber and Hoel 2015: 190).

$$Crash\ Rate\ per\ million\ entering\ vehicles\ (RMEV) = \frac{Crashes\ per\ year \times 1000000}{Annual\ Average\ Daily\ Traffic} \tag{2}$$

As crash rates may overemphasize 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.

## 3.1 Statistical Analysis

As the objective is to determine if a statistically significant relationship exists between the two samples, namely traffic volumes and accident counts the, appropriate statistical test would include a linear regression analysis. The use of this method is supported by (Rakha et al. 2010:21) who indicates that this approach can be applied to crash data to develop crash prediction models to predict future observations of “y” (accident counts) corresponding to a specified value for the dependent variable “x” (traffic volumes) (Montgomery & Runger 2014:434). The null and alternative hypotheses for this study are as follows:

$H_0$ (null): Traffic volumes per intersection control type do not affect traffic accidents. The slope co-efficient of traffic volumes is zero.

$H_a$ (alternative): Traffic volumes per intersection control type do affect traffic accidents. The slope co-efficient of traffic volumes is positive.

## 3.2 Validation and Significance of the Model

The linear regression model was tested for goodness of fit and to further check assumptions by residual analysis to confirm residuals as being normally distributed. The assessment of the significance of the regression model would include the Analysis of Variance (ANOVA) statistical method. The procedure comprises the t-test and f-test where the total variability in the dependent 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.

## 4. DATA ANALYSIS AND FINDINGS

It is important to note that crash rates are not dependent 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 2000: 27). For example, crash rates may increase or decrease as the standard deviation of speed increases or with variations in the traffic flow rate. Although the application of a simple linear regression model involving one independent variable and one dependent variable may not be capable of fully explaining the effect of changes or interactions of additional variables on the crash rate, the model would be suitable as a “first step” screening method in identifying and selecting intersections requiring more detailed assessments or audits.

The average accident rates per intersection control type are shown in Table 2, and indicate a preliminary relationship between accidents and traffic volumes, with the exception of traffic signals located in the central business district (CBD) and traffic circles which requires further interpretation. In this regard it is important to note that traffic circles and traffic signals (CBD) are polar opposites in terms of the number of intersection conflict points. Traffic circles by design typically have 8 vehicle to vehicle conflict points. Traffic signals (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 exposure rates.

Through this study it was found that an often-overlooked aspect in both national and international road safety studies is that pedestrian counts and other non-motorized transport modes (NMT) are not assessed with motorized traffic counts and therefore are not a true reflection of exposure in terms of accident rates. The Accident Severity rate as shown in Table 2 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 2: 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 | 9 535 | 0,66 | 0,91 |
| Traffic circle | 9 | 12 861 | 1,02 | 1,63 |
| Priority Control | 31 | 7 708 | 1,25 | 2,53 |
| Traffic signal | 42 | 43 171 | 2,35 | 3,37 |
| Traffic signal - CBD | 9 | 28 692 | 4,70 | 6,51 |

Intersections with similar levels of ADT were then identified and averaged for each intersection control type. Intersections were selected by means of a sliding window method and assessed over the consecutive ADT counts. In terms of data analysis, a sliding window technique was used in order to select those intersections with the most similar ADT in comparison with the different intersection control types. The intersection data were grouped according to intersection control type and arranged according to increasing ADT. The ADT data was then analyzed in smaller subsets of intersections or a moving average of three or four intersections until the subset window or moving average for each intersection control type approached similar ADT levels. The objective of this analysis was to compare the safety performance of different intersection control types with similar ADT's. This is shown in Table 3. The accident severity rate is comparable for all-way controlled (1.13), traffic circle controlled (1.39) and priority controlled (1.63) intersections. 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 0.8. 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 non-motorized transport (NMT) conflicts contributing to accidents. While the summarized data in Table 2 and Table 3 are represented by averages and provides a preliminary view into the accident rates, it will be the task of the linear regression model to validate the statistical significance of the accident data associated with the various intersection control types.

**Table 3: 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 | 4 | 17158 | 0,80 | 1,13 |
| | Int. Panorama & Kestrel | | | | |
| | Int. Theuns Van Niekerk & Underberg | | | | |
| | Int. Heuwel & Suid | | | | |
| Traffic Circle | Int. Braam Pretorius & Dr Swanepoel | 3 | 16548 | 0,83 | 1,39 |
| | Int. Lois & Ingersoll | | | | |
| | Int. Maunde & Makaza | | | | |
| Priority Control | Int. Pierneef & 21st | 4 | 18441 | 0,76 | 1,63 |
| | Int. Rooihuiskraal & Kolgans | | | | |
| | Int. Saxby & Cradock | | | | |
| | Int. Francis Baard & Farenden | | | | |
| Traffic Signal | Int. Van Ryneveld & Van der Spuy | 3 | 18866 | 1,31 | 2,04 |
| | Int. Glenwood & Oberon | | | | |
| | Int. Moot & Hendriks | | | | |
| Traffic Signal - CBD | Int. Kgosi Mampuru & Bloed | 4 | 19782 | 5,71 | 7,73 |
| | Int. Robert Sobukwe & Nelson Mandela | | | | |
| | Int. Bosman & Jeff Masemola | | | | |
| | Int. Lilian Ngoyi & Boom | | | | |

The data for all 112 accidents are shown in Figure 4. A linear regression line is superimposed on the data. A positive linear relationship between the variables is evident. The presence of outliers may be expected considering the various other factors which may affect the independent variable. Future research may expand the scope of the study to include additional variables such as conflict points and traffic congestion (V/C) by means of a multiple linear regression model. 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.

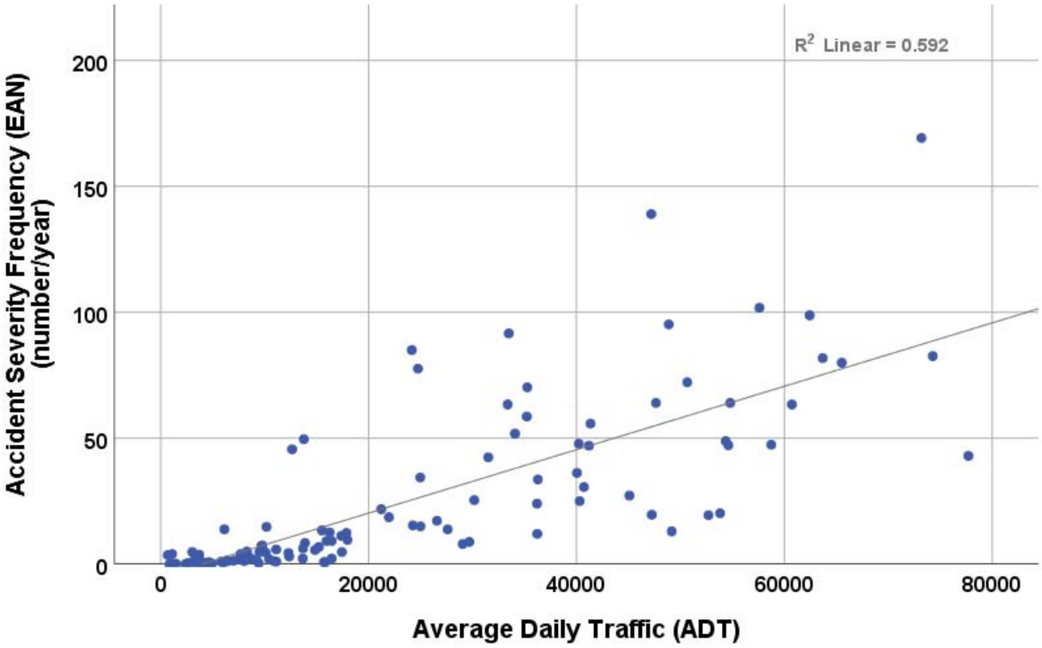



**Figure 4: Scatter plot with fitted regression line**

The $R^2$ value of 0.592 indicate a strong "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. Values of $R^2$ between 0.50 to 1.00 or -0.50 to -1.00 generally indicate a large or strong correlation (Cohen 1988: 413). The equation provided by the model 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 equation and values of the slope and intercept terms for the regression line is provided as follows:

Accident Severity Frequency = -4.908 + 0.0012*ADT

Forcing the intercept term to zero would not be recommended as it would negatively affect the model viability and $R^2$ value.

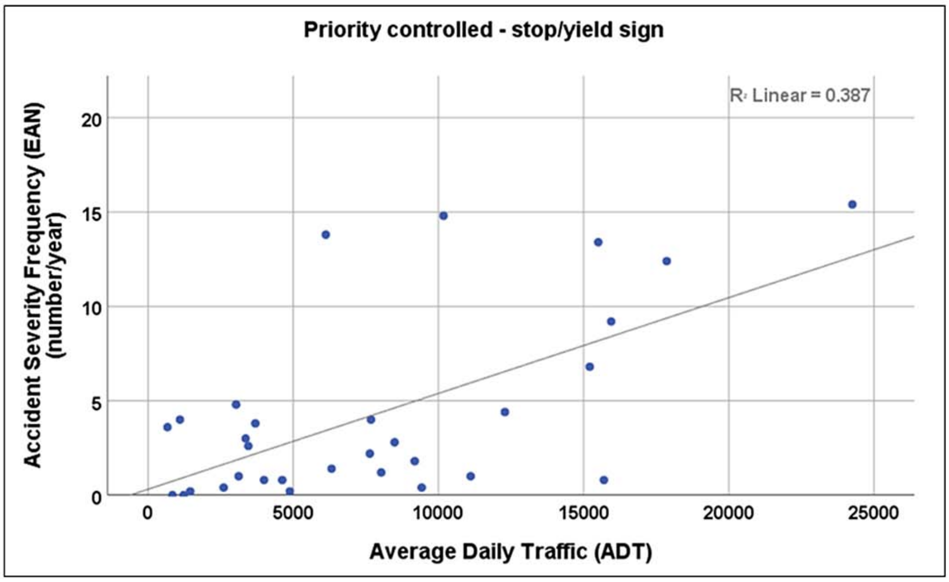



**Figure 5: Accident severity frequency scatter plot for priority-controlled intersections**

In this manner linear regression models were developed for all intersection control types. For example, the scatter plot for priority-controlled intersections is shown in Figure 5, which is a subset of the combined graph primarily highlighting ADT's up to 25 000 ADT. The $R^2$ value of 0.387 indicates a moderate "goodness of fit" of the model, the lower correlation value may be indicative of the smaller sample size of the intersection control type. The equation for the regression line is presented as follows: Accident Severity Frequency = 0.314 + 0.0005*ADT.

## 5. CONCLUSION AND RECOMMENDATIONS

In the South African context, further research is required from municipalities and local 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 conditions as well roadway and environmental conditions.

This research has highlighted new insights not alluded to in the literature review. The results qualitatively infer that intersection conflict points may play a significant role in the number and severity of accidents recorded. In this regard intersections with high pedestrian volumes and other non-motorized transport modes (NMT) contribute significantly to greater road safety risks. In addition to high pedestrian volumes the non-uniform, sometimes unpredictable driver and road user behavior exacerbates the high accident rates shown in the Pretoria Central Business District (CBD).The linear regression equations and models as developed through this study allows for the prediction of new or future accident counts corresponding to a specified traffic volumes. In this regard a linear regression model may be developed for the various intersection control type's namely priority-controlled intersections, all-way controlled intersections, traffic circle-controlled intersections, traffic signal-controlled intersections, traffic signal-controlled intersections in the Pretoria CBD and finally all intersections control types combined. However, the recommendations for future research would be to increase the sample size specifically for traffic circles and traffic signals (CBD) in order to develop significant regression models for these intersection control types. It is further recommended that multiple linear regression models be considered in order to account for additional variables such as conflict points and traffic congestion in terms of V/C ratios. The linear regression equations now developed enables CTMM officials or other researchers to analyze, predict and prioritize intersections for more detailed road safety assessments or audits. In this manner scarce municipal funds can be allocated to high benefit, low-cost projects that would allow for greater reductions in road accidents. This prioritization enables the overall strategy towards proactively managing road safety on an objective basis rather than a reactive, inefficient "fire-fighting" approach.

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