INFLUENCE OF ROAD GEOMETRIC AND TRAFFIC FEATURES ON ROAD SAFETY

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ABSTRACT

Road traffic crashes are one of the major causes of death and injury worldwide, with estimates showing that over 1.3 million road users die every year globally on the world's roads, and approximately 30 times as many sustain non-fatal injuries. The road traffic crashes burden is felt disproportionately more in developing countries, where road and traffic conditions differ significantly from developed countries. Road user perceptions are influenced by roadway features and play a vital role in determining the crash risk levels on the roads. This study investigated roadway features on surfaced roads with gravel shoulders that play a prominent role in influencing the occurrence of road traffic crashes on rural roads on the Namibian national road network.

The compliance of the physical road features with typical road design standards was determined against those set by the Technical Recommendations for Highways 17 on the Geometric Design of Rural Roads (TRH 17) used in Namibia for some time. The compliance assessment found that road shoulder and lane widths on the studied road sections did not comply with TRH17. The study also developed multivariate road crash prediction models (CPMs) to investigate the statistical significance of the link between road crash incidence and selected road features.

The CPMs identified several interactive relationships between road section lengths, lane widths, shoulder widths, 85th percentile speeds and horizontal curve radii that significantly influence the occurrence of road crashes on the road section. By extension, the CPMs developed will assist transportation safety authorities in identifying road features influencing crash incidence and implementing appropriate road safety measures with the intent to promote a safer road system.

1. INTRODUCTION

1.1 Background

Road crash statistics reported in 2015 indicated that Namibia's road fatality rate ranks among the highest on the African continent at 31.1 fatalities per 100 000 population (Figure 1) (Namibia Statistics Agency, 2015). The period 2011 to 2015 recorded a compounded increase in fatalities of 4%. Moreover, with an expected increase in rural road traffic volumes, traffic safety is expected to continue being a serious concern for traffic safety authorities in Namibia (Ambunda & Sinclair, 2019). The high number of road traffic fatalities is a major socio-economic drawback for most developing countries including Namibia (Madejski & Jackie, 2017).

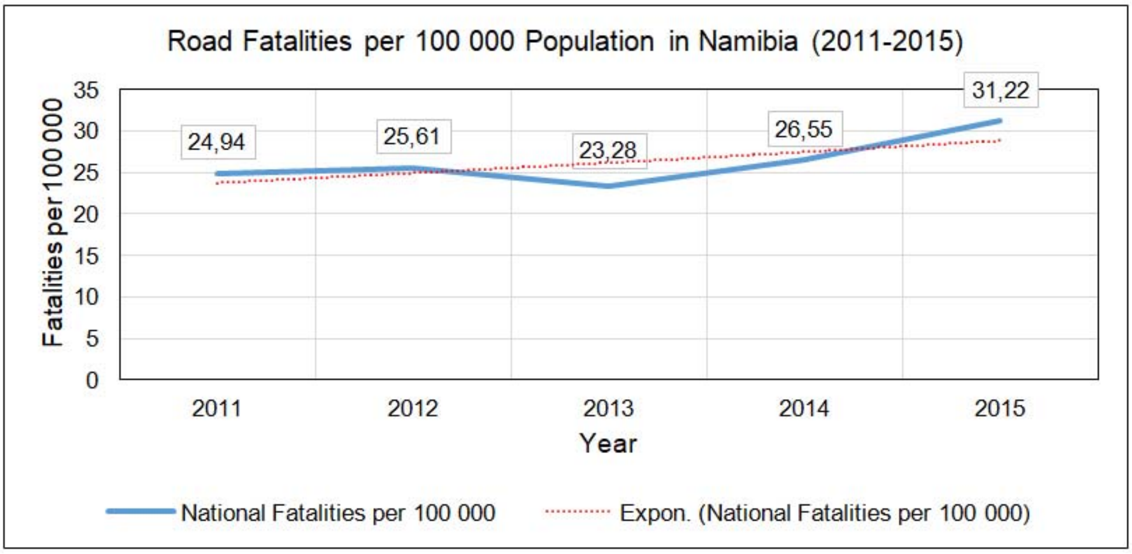

Figure 1: Road crash fatalities per 100 000 population in Namibia (2011-2015)

Road traffic crashes occur as a result of a combination and interaction of several interrelated factors, including road user behaviour, the road environment and vehicle related factors (Shalom Hakkert & Gitelman, 2014; Stephan & Newstead, 2017). It is also generally recognized that the road features and environment play a significant role due to their impact on road user perceptions (Ellison*et al.,* 2015; Hjelkrem & Ryeng, 2017).

Road features are designed taking into consideration average driver behaviour, reactions and traffic conditions (Mackie *et al.*, 2013; Herrstedt, 2015). Driver behaviour, however, is the direct result of how a driver 'reads' the road environment and determines what driving behaviour is appropriate given the physical environment. In this way, driver behaviour is directly and immediately influenced by the combination of road design features and traffic conditions.

Road safety literature is replete with studies investigating the influence of single road design and traffic features on road safety – for example, the effect of the provision of a hard shoulder on driver perception and hence road safety (Ben-Bassat & Shinar, 2011; Gitelman *et al.*, 2019). Yet design features work in parallel with each other – a hard shoulder is only one design detail among others which include lane width, horizontal and vertical curvature, pavement design, road marking and so forth (Hanno, 2004; Edquist *et al.,* 2009; Ambunda & Sinclair, 2019). There is very little information on the effect of various combinations of design features on road safety.

Prevailing traffic flow offers another dimension to the information received and interpreted by the driver – the prevailing speed and traffic volumes, the proportion of heavy goods vehicles etc. (Choudhary *et al.*, 2018; Pešić *et al.*, 2019). All these factors together determine how the road environment is perceived and what behaviour then emerges.

To achieve a systematic and sustainable reduction in road fatalities, it is important to address road safety issues relating to all three major traffic safety pillars; humans, vehicles and road environment (Ambunda & Sinclair, 2019). In this respect, a vital aspect of addressing road safety issues is identifying crash locations, to understand the potential road safety link between driver behaviour and perceptions, and the road features (Ambunda, 2018).

1.2 Problem Statement

Namibia is faced with the reality of an increase in the frequency of fatal injury crashes, despite the roadway infrastructure being considered to be in good condition. Research investigating the influence of the rural road design and traffic environment on crash risk levels is mostly dominated by work in developed countries, with a huge gap on similar studies in developing countries, where road and traffic conditions differ immensely from those in developing countries.

Most developing countries, including Namibia, are faced with a lack of locally tested or developed tools to predicts and investigate crash incidence. Moreover, little is known on the extent of the link between the rural road design and traffic conditions and road crash incidence on the Namibian road network.

2. PURPOSE OF STUDY

In view of the foregoing, the purpose of this study was three-fold:

- Firstly, to identify road crash hotspots related to fatal crashes on the national rural road network in Namibia by employing geospatial analysis methods.
- Secondly, the study assessed the compliancy of road design features on the identified sections with road design standards used in Namibia.
- Finally, the study investigated the combinational effect of the road design standards assessed on road safety through CPMs with the view of making recommendations to road safety stakeholders.

3. DATA AND METHOD

3.1 Data

Fatal road crash information on the Namibian national road network for the period 2014 to 2016 was obtained from Namibian National Road Safety Council (NRSC). Information on the geometric design of road features and traffic conditions on the identified rural road sections was obtained from the Roads Authority of Namibia (RA). The road crash locations in the crash data sourced were described using landmarks close to the roadway. Therefore, during geocoding, the closest kilometer marker on the road landmark mentioned in the crash data was noted as the crash location.

Seven (7) road design and traffic aspects (Table 1) on the identified high-risk crash locations (hotspots) were selected for the study due to the quality and quality of information provided by the RA. The study then assessed the compliancy of the information on the features provided, with TRH17 and investigated the effects of their interactive relationship on road safety. A much wider range of roadway information is considered necessary for further studies, but the seven listed aspects provided an opportunity to set up a methodology and make provisional conclusions.

Table 1: Road design and traffic variables

Variables	SI Units
Annual Average Daily Traffic (AADT)	Veh/365 days
85^{th} Percentile operating speed (Sp)	Km/hour
Number of lanes(L)	Count
Lane width (LW)	Metres
Shoulder width (SW)	Metres
Horizontal curves radii (HCRAD)	Metres
Section length (SL)	km

The minimum requirements for the TRH 17 (Table 2) were used to investigate the level of compliancy considering the different traffic and speed conditions on the rural roads. It is important to note that although new geometric design standards are applied in Namibia, reference is made to TRH 17 as the road examined were built following the guidelines set in TRH 17.

Table 2: TRH 17 minimum requirements for rural road design

Road element	TRH 17 Recommendation
Minimum horizontal curve radius	530m
Speed limit	120km/h
Lane width	3.5m
Number of lanes	2
Shoulder width	2.0m

3.2 Method

3.2.1 Identification of Crash Hotspots

The study applied a spatial visualisation technique for the geospatial analysis, employing a Geographical Information System. The planar kernel density estimation (KDE) was applied to visualise where clusters of fatal road crashes had happened during the analysis period of 2014 to 2016. The bandwidth and grid size were two key parameters that influenced the results of the hotspot analysis. Five different bandwidth values were tested (200m, 400m,800m and 1 000m), with a better visualization of road crash hotspots on a grid size of 30m by 30m achieved at a bandwidth of 1 000m. The KDE tool produced a raster map (Figure 2), showing the density of road fatalities in colour shading, with the five highest sites/ sections numbered, where the density of the road crashes is displayed by continuous surfaces and the locations with the highest crash density are numbered.

The crash rates (Equation 1) on the identified sections were calculated and found to be the highest on these rural road sections during 2014 to 2016, with crash rates ranging from 0.21 to 0.29 fatal crashes per million vehicle kilometres travelled.

$$CR = \frac{RTC \times 10^6}{AADT \times 365 \times T \times L} \quad (1)$$

Where; CR = Crashes per million vehicle kilometres travelled
RTC = Number of fatal road crashes
AADT = Average Annual Daily Traffic
L = Length of study sections (kms)
T = Duration of study period (years)
365 = Number of days/ year

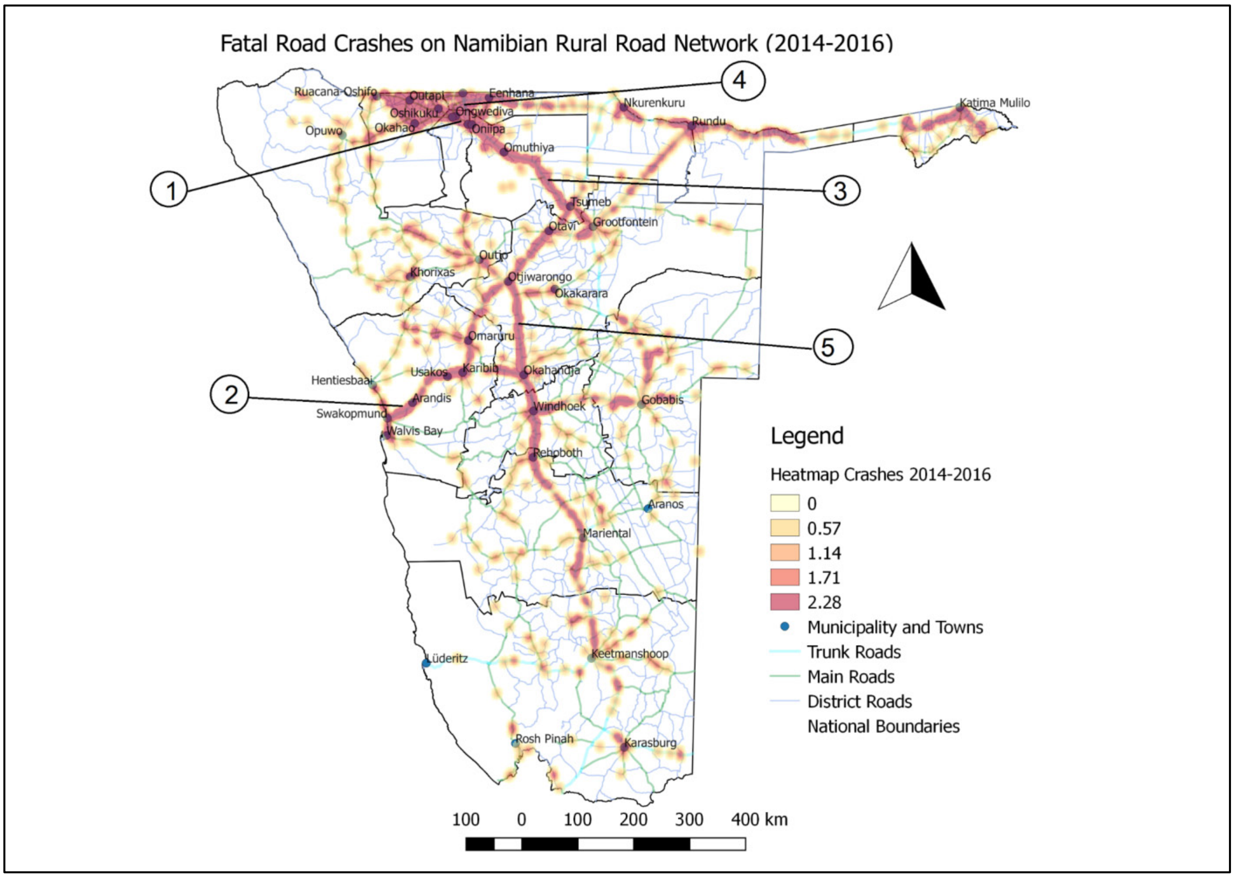

Figure 2: Fatal road crashes on Namibian rural road network (2014-2016)

Three of the five most hazardous rural road sections (Table 3) were selected for further analysis from the heat map.

Table 3: Road sections with highest crash risk level

No.	Road segment	Road length (km)	Crash rate ($CRx10^6$)
1	M0092 (Ondangwa-Oshakati)	24.80	0.29
2	T0202 (Arandis-Swakopmund)	43.14	0.27
3	T0110 (Tsumeb-Oshivelo)	84.95	0.24
4	T0112 (Ondangwa-Eenhana)	35.80	0.22
5	T0107 (Okahandja-Otjiwarongo)	164.60	0.21

3.2.2 Development of CPMs

Due to the independent and random nature of road crashes, the CPMs were developed using a parametric data analysis method known as Negative Binomial Regression (NBR) (Equation 2). NBR allows for the variance of the dependent variable to be greater than the mean, which is a limitation for simple multiple linear regression and Poisson regression models.

$$ln\mu = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \quad (2)$$

Where the predictor variables x_1, x_2,.....,x_p are given for the analysis, and the population regression coefficients β_0, β_1, β_2,.....,β_p are to be estimated for the Negative Binomial Regression Model.

The significance of the relationships identified by the CPMs is determined by the probability value (model p-value). A statistically significant relationship is determined if the p-value is equal to or less than the alpha value set at 0.05. The strength of the interactive relationship is indicated by the B parameter and correlation coefficient R^2 computed by the CPMs, with its significance determined by p-value. The “p-value” in the study results represents the performance of the individual feature in the model, while the “model p-value” represents the overall model performance (combination of road features).

4. RESULTS AND DISCUSSION

4.1 Ondangwa-Oshakati (M0092)

4.1.1 TRH 17 Compliance Assessment (M0092)

The road design compliance assessment (Table 4) found that all the horizontal curve radii (≥ 530m) on the road section are compliant with the TRH17. The recorded AADT on the study section was 9 399 vehicles, with an 85th percentile operating speed (103.5km/h) is within the speed limit (120km/h) on the road section. The assessment found that the lane width on the road section (2.91m) is less than the recommended lane width (3.5m) by the TRH 17. Similarly, the shoulder width on the section (1.01m) is far less than the recommended shoulder width (2.0m) as recommended by TRH 17. The road section has the recommended number of lanes for its classification type, speed and traffic volume conditions.

Table 4: Road design compliance assessment on section M0092

Road element	TRH 17	Existing Condition
Minimum horizontal curve radius	530m	>530m
Speed limit/ 85th percentile speed	120km/h	103.53km/h
Lane width	3.5m	**2.91m**
Number of lanes	2	2
Shoulder width	2.0m	**1.01m**

4.1.2 CPMs Results (M0092)

CPMs results for the road section M0092 are presented in Table 5.

Table 5: CPMs information on section M0092

Variable combination	Significant variable	P-value	B-value	Model P-value	Model Adjusted R^2
LW & SW	SW	0.0031	-10.4372	0.0001	0.8205
LW, Sp & SL	LW	0.0217	-4.7614	0.0000	0.9122
	Sp	0.0069	1.371		

The results show that the combination of lane width and shoulder width has a statistically significant (p value= 0.0001) influence on fatal crash incidence, accounting for slightly more than four fifths (82.1%) of variance in the CPM. The shoulder width exhibited a significant negative correlation (p value= 0.0031; B= -10.4372) with crash incidence on the section. A statistically significant (p value= 0.0000) combinational effect on road crash incidence was also identified between lane width, the 85th percentile operating speed and section length, accounting for more than nine tenths (91.2%) of the variance in road crash incidence on the road section. A significant negative correlation with road crash incidence was demonstrated by lane width (p value= 0.0217; B= -4.7614) in the CPM, while a significant positive correlation was demonstrated by speed (p value= 0.0069; B= 1.371) with road crash incidence on the road section.

4.2 Arandis-Swakopmund (T0202)

4.2.1 TRH 17 Compliance Assessment (T0202)

The TRH 17 design standard compliance assessment on T0202 (Table 6) found all the horizontal curves on the study section complied with the minimum radius (≥ 530m).The Annual Average Daily traffic was recorded as 10 655 vehicles, with 85th percentile operating speeds (114.53km/h) on the road section lower than the speed limit (120km/h) on section. Also, the number of lanes (2) is compliant with the recommended lanes (2). The study found that the road section lane width (2.35m) is not compliant with the TRH 17 recommended width (3.5m). It seems this section was a low volume strip road (one lane) that was remarked to two lanes without prior consideration of the safety risks involved. Also, the shoulder width (0.95m) on the road section is not compliant with the TRH 17 recommendations (2.0m) for the road classification.

Table 6: Road design compliance assessment on section T0202

Road element	TRH 17	Existing Condition
Minimum horizontal curve radius	530m	>530m
Speed limit	120km/h	114.53km/h
Lane width	3.5m	**2.35m**
Number of lanes	2	2
Shoulder width	2.0m	**0.95m**

4.2.2 CPMs Results (T0202)

The CPM results for the combinations on section T0202 are shown in Table 7.

Table 7: CPMs information on section T0202

Variable combination	Significant variable	P-value	B-value	Model P-value	Model Adjusted R^2
LW & SW	SW	0.0002	-14.0025	0.0000	0.6602
HCRAD & LW	HCRAD	0.0000	-0.3743	0.0024	0.6991
	LW	0.0031	-0.0032		
SW &Sp	SW	0.0332	-3.4273	0.0000	0.8123
	Sp	0.0015	2.4825		

The results indicated that the combinational effect of lane width and shoulder width on fatal crash incidence is significant (p value= 0.000). The interactive relationship accounted for more than three fifths (66%) of the variance in the CPM, with the shoulder width demonstrating a significant negative correlation (p value= 0.0002; B= -14.0025). The results also showed a statistically significant (p value= 0.0024) impact on road crash incidence by the interaction of horizontal curve radii and lane widths on the road section. The relationship accounted for close to seven tenths (69.9%) of the variance in the CPM, with the horizontal curve radii and lane width demonstrating significant negative correlations (p value= 0.0000, 0.0031; B= -0.3743, -0.0032 respectively) in the CPM. The CPMs also showed that the combination of shoulder width and 85th percentile operating speed significantly (p value= 0.0000) influenced fatal road crash incidence on the road section, accounting for slightly more than four fifths (81.2%) of the variance in the model.

The shoulder width and 85th percentile speeds variables were also statistically significant (p value= 0.0332, 0.0015 respectively) in the CPM, albeit showing opposite correlations (B= -3.4273, 2.4825 respectively) with crash incidence.

4.3 Tsumeb-Oshivelo (T0110)

4.3.1 TRH 17 Compliance Assessment (T0110)

The road design compliance assessment on T0110 (Table 8) found all the horizontal curve radii on the road section compliant with the TRH 17 recommendation (≥ 530m). Of the three study sections, the lowest AADT (3 991 vehicles) was found on this road section, with an 85th percentile operating speed (110.12km/h) was also found to be lower than the speed limit (120km/h) on the section. Similarly, the number of lanes (2) and shoulder width (2.01m) were found to be compliant to with TRH 17 design recommendation for number of lanes (2) and shoulder width (2.0m). On this section (T0110), the lane width (2.81m) did not comply with the width (3.5m) recommended by the TRH 17 for the road's classification, speed and traffic conditions.

Table 8: Road design compliance assessment on section T0110

Road element	TRH 17	Existing Condition
Minimum horizontal curve radius	530m	>530m
Speed limit	120km/h	110.12km/h
Lane width	3.5m	**2.81m**
Number of lanes	2	2
Shoulder width	2.0m	2.01m

4.3.2 CPMs Results (T0110)

The results of the CPMs (Table 9) identified a statistically significant (p value= 0.0008) interactive relationship between lane width (LW) and 85th percentile operating speed (Sp) influencing road crash incidence on section T0110, with the variables accounting for slightly less than nine tenth (87.2%) of the variance in fatal road crash incidence. Statistically significant negative correlation was demonstrated by the lane width variable (p value= 0.0022; B= -11.0116) on road crash incidence on the road section. The CPMs also found a statistically significant (p value=0.0249) interactive relationship between the horizontal curve radii, lane width and shoulder width, accounting for slightly more than half (51.9%) of the variance in road crash incidence on the road section. The shoulder width (p value= 0.0000; B= -0.9783) and lane width (p value= 0.0007; B= -2.0151) variables in the CPM demonstrated significant negative correlations with road crash incidence.

Table 9: CPMs information on section T0110

Variable combination	Significant variable	P-value	B-value	Model P-value	Model Adjusted R^2
LW & Sp	LW	0.0022	-11.0116	0.0008	0.8721
HCRAD, LW& SW	SW	0.0000	-0.9783	0.0249	0.5192
	LW	0.0007	-2.0151		

5. CONCLUSIONS

The study assessed the compliance of a number of rural road features with the Technical Recommendations for Highways (TRH 17) on the Geometric Design of Rural Roads, and developed crash predictive models (CPMs) to investigate the combinational effects of the road variables on fatal road crash incidence.

A hotspot analysis using planar Kernel Density Estimation (KDE) technique in QGIS identified three rural road sections for investigation. The highest crash rate (0.29 fatal crashes per million vehicle kilometres travelled) was found on the Ondangwa to Oshakati rural road section, while the crash rates were 0.27 and 0.24 fatal crashes per million vehicle kilometres travelled on the Arandis to Swakopmund and Tsumeb to Oshivelo rural road sections.

A road design compliance assessment found the lane widths on all three study sections not compliant with the TRH 17, for the road classifications, traffic speed and volume conditions existing on the sections. Similarly, certain road sections were found to be non-compliant with TRH 17 with regard to road shoulder width. The study found that the 85th percentile operating speed on all section was lower than the speed limit. The design speeds for these road sections are not known and hence no firm conclusions could be drawn in this regard.

The combinational effect of the road features on road safety was investigated in the CPMs developed. On section M0092 (Ondangwa-Oshakati), the CPMs identified two statistically significant interactive relationships. An interactive relationship between lane width and shoulder width demonstrated a significantly high correlation with road crash incidence, with the shoulder width variable significantly influencing road crash incidence in the CPM. The combinational effects of lane width, 85th percentile operating speed and section length was also found to be statistically significant on M0092, with the lane width and speed variable exhibiting significant effects on road crash incidence. Lane width and shoulder width featured as common variables in the CPM relationships found. Possibly, this could be attributed to their non-compliance with the TRH 17.

On section T0202 (Arandis-Swakopmund), three statistically significant CPM variable combination relationships were identified:
(i) lane width and shoulder width,
(ii) horizontal curve radii and lane width, and
(iii) shoulder width and 85th percentile operating speed.

Similar to the relationships identified on M0092, the lane width and shoulder width featured in all the relationships, exhibiting statistically significant impacts on road crash incidences on the section.

The CPM results on section T0110 (Tsumeb-Oshivelo) identified two statistically significant relationships between road features and fatal crash incidence. The combination of lane width and 85th percentile operating speed exhibited a high correlation with crash incidence, compared with the combination of horizontal curve radii, lane width and shoulder width. Similar to CPM relationship on other sections investigated, the lane width and shoulder width combination significantly influenced crash incidence on the road section.

The study results motivate the urgent need to address the non-compliance of road design variables, to further investigate the impact of road features on road safety and re-evaluate road safety remedial measures in a bid to proactively address road safety issues.

6. REFERENCES

Ambunda, R, 2018. 'Analysis of the Relationship between Fatal Rural Road Crashes and Road Design Elements : Namibian Case Study'.

Ambunda, R & Sinclair, M, 2019. 'Effect of Two-Lane Two-Way Rural Roadway Design Elements on Road Safety', *International Journal of Innovative Technology and Exploring Engineering*, 8(4):632-637.

Ben-Bassat, T & Shinar, D, 2011. 'Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior', *Accident Analysis and Prevention*. Elsevier Ltd, 43(6):2142-2152. doi: 10.1016/j.aap.2011.06.004.

Choudhary, P, Imprialou, M & Velaga, NR, 2018. 'Impacts of speed variations on freeway crashes by severity and vehicle type', *Accident Analysis and Prevention*. Elsevier, 121:213-222. September. doi: 10.1016/j.aap.2018.09.015.

Committee of State Road Authorities, 1988. 'Geometric Design of Rural Roads', in *Technical Recommendations for Highways, TRH 17*. Pretoria, South Africa: Department of Transport.

Edquist, J, Rudin-Brown, C & Lenne, M, 2009. *Road Design Factors and their Interactions with Speed and Speed Limits*. Victoria.

Ellison, AB, Greaves, SP & Bliemer, MCJ, 2015. 'Driver behaviour profiles for road safety analysis', *Accident Analysis and Prevention*. Elsevier Ltd, 76:118-132. doi: 10.1016/j.aap.2015.01.009.

Gitelman, V, Doveh, E, Carmel, R & Hakkert, S*,* 2019. 'The influence of shoulder characteristics on the safety level of two-lane roads: A case-study', *Accident Analysis and Prevention*. Elsevier, 122:108-118. February 2018. doi: 10.1016/j.aap.2018.10.003.

Hanno, D, 2004. *Effects of the Combination of Horizontal and Vertical Alignments on Road Safety*. The University of British Columbia.

Herrstedt, L, 2015. *The Basis of "The Self-Explaining Road"*. Copenhagen.

Hjelkrem, OA & Ryeng, EO, 2017. 'Driver behaviour data linked with vehicle, weather, road surface, and daylight data', *Data in Brief*. Elsevier Inc., 10:511-514.
doi: 10.1016/j.dib.2016.12.036.

Mackie, HW, Charlton, SG, Baas, PH & Villasenor, PC*,* 2013. 'Road user behaviour changes following a self-explaining roads intervention', *Accident Analysis and Prevention*. Elsevier Ltd, 50:742-750. June. doi: 10.1016/j.aap.2012.06.026.

Madejski, EA & Jackie, LL, 2017. 'Investigating the impact of reckless driving, traffic law enforcement and road crash statistics in Namibia', 2597(061):1-11.

Namibia Statistics Agency, 2015. *Namibia Social Statistics 2010 - 2015*. Windhoek.

Pešić, D, Antic, B, Smailovic, E & Bojana, T*,* 2019. 'The impact of the average traffic flow speed on occurrence risk of road crash', *Put i Saobraćaj*, 65(2):29-36. doi: 10.31075/pis.65.02.05.

Shalom Hakkert, A & Gitelman, V, 2014. ‘Thinking about the history of road safety research: Past achievements and future challenges’, *Transportation Research Part F: Traffic Psychology and Behaviour*. doi: 10.1016/j.trf.2014.02.005.

Stephan, K & Newstead, S, 2017. ‘Measuring the Influence of the Road and Roadside in the Safe System’, pp. 1-11.