THE IMPACT OF EXISTING AND "IDEAL" ROAD DESIGN CHARACTERISTICS ON ROAD SAFETY: THE CASE OF NAMIBIA

R AMBUNDA[1] and M SINCLAIR[2]

[1]Department of Civil and Mining Engineering, University of Namibia, Namundjembo Mengela Street, Ongwediva, Namibia; Email: rambunda@unam.na
[2]Department of Civil Engineering, Stellenbosch University, Bosman Street, Stellenbosch

ABSTRACT

The design of roads plays a significant role in road safety outcomes. Typically, road safety is considered as just one of many considerations in road design and is often not prioritised. The study aimed to assess the relationship between existing and ideal road design and traffic environment, and the frequency of Fatal and Serious Injury (FSI) road crashes in the Namibian context. The assessment (sensitivity analysis) was carried out using developed context-specific Generalised Poisson Crash Prediction Models (GP-CPMs). The results from the sensitivity analysis were concerning, as they indicated that despite the application of standard-compliant design parameters in the crash models, several model covariates demonstrated pronounced combinational effects detrimental to the safety of the road system. The results indicate how important it is to re-assess the relevance of "international" design guidelines, to ensure their relevance in a local road environment and also to the behavioural characteristics of road users.

Keywords: Crash predictive models, Road design, Design guidelines, Road safety, Namibia.

1. INTRODUCTION AND BACKGROUND

1.1 Background

The Technical Recommendations for Highways 17 (TRH 17) on the Geometric Design of Rural Roads (Committee of State Road Authorities (CSRA), 1988) recognise road design standards as vital principles to guide and control the design of the roadway. The Policy on Geometric Design of Highways and Streets (American Association of State Highway and Transportation Officials (AASHTO), 2011) reports that design standards are aimed at providing operational efficiency, safety, comfort and convenience to road users. Some flexibility in the road design standards allows for localised solutions for numerous functional and operation requirements (Semar, 2003). However, Slop (1994) states that allowing space for interpretation may unintentionally lead to an application of different road designs in the same road area, which may cause safety issues (Weller *et al.*, 2008). Also, road design cannot be considered safe or fit for purpose if it simply adopts minimum requirements, particularly in combination with other design elements. Most design criteria have been developed in isolation from each other (despite some implicit relationships), and when applied in combination with other elements, may result in "context" solutions that compromise the safety of users (Mitra *et al.*, 2021).

The unsuitability and inability of large parts of the road network to fulfil the combination of functions they are designed for play a role in the hazardous road safety situation in various regions of the world (Kopits & Cropper, 2005; Khayesi and Peden, 2005). Pinard *et al.* (2003) argue that adopting road design standards from developed countries to address the precarious road safety situation in developing countries is considered a misjudgement. In developed countries, design standards are generally backed by road safety training and traffic law enforcement, which is often not the case in developing countries (Eggleston, Hansen & Carrera, 2016). Additionally, the traffic and road characteristics in developing countries differ greatly from those in developed countries (Agerholm *et al.*, 2017).

Over the years, it has been assumed that design standards and norms, as they evolved, were developed from a solid base of research, with road safety as a major consideration for the design standards and the road elements (Thomas *et al.*, 2013). However, during the past decades, the changing parameters of vehicles and the changing public attitudes have brought into question the solid foundations of the design norms (Padmanaban *et al.*, 2010). In fact, Ezra Hauer, in 1999, suggested that many of the design standards that we use today are based, not on scientific evidence of failure (and hence lack of safety), but on conjecture about the preconditions for error. He writes: “Conjectures, no matter how plausible, are not usually acceptable when it comes to matters affecting health. Thus, e.g., a drug will not be approved for use unless its effect is carefully tested and its curative benefits as well as harmful side effects are known. Yet, the design of vertical crest curves is based not on empirical fact but on plausible conjecture. By founding road design on an unproven conjecture, the link between reality and road safety (as measured by crash frequency and severity) has been severed”. In a similar vein, Abele & Møller (2011) note that design standards that shape the road system are developed with safety in mind, but in some instances without quantitative knowledge of the link between the engineering decisions and their safety consequences.

Despite the acknowledgement of safety as a vital aspect of roadway design, empirical research necessary to establish the relationships between roadway geometry and safety remains limited. Where they exist their findings are sometimes contradictory, and so far appear insufficient to establish firm scientific and practically desirable relationships that remain valid in all circumstances (Slop, 1994). Most developing countries, including Namibia and many of its neighbours, are faced with a lack of tools to predict and investigate crash likelihood along their road network. As a result, road safety authorities tend to be reactive instead of proactive to road safety issues. Moreover, little is known of the influence that the national rural road environment has on the occurrence of road crashes and the level of crash severity, as no literature was found in relation to the extent of the combinatorial relationship between road design elements and traffic characteristics on the crash risk level.

Due to the lack of local studies on the relationship between road safety and the combination of road elements, the Namibian authorities responsible for compiling road design standards have relied heavily on their own judgements or standards imported from other countries, in the absence of appropriate local sources. This stance is one that is adopted commonly across most African countries. Arguably, however, the absence of locally-derived standards and the potential non-accordance of the adopted road design standards for the road network in Namibia increases the risks and contributes to the precarious road safety problem.

1.2 Study Objective

The main objective of this study was to assess the impact of design compliance on various classifications of national roads impacts road safety in Namibia. This investigation was done by applying a tool (the Namibian context-CPM tools were developed in studies by Ambunda (2021) and Ambunda and Sinclair (2022)) to compare and quantify the extent of the link between existing and recommended design characteristics, and fatal and serious injury crashes on the selected roads.

1.3 Study Relevance

The study insights improve the understanding of the combinational effects of road design and traffic attributes on national road fatal and serious injury crashes. Although the work was carried out using crash data from a single African country, it has built a foundation on which the sensitivity of crash risk factors can be tested against changes in road parameters in other parts of the continent as well. The tool (developed in the study by Ambunda (2021)) also allows for the identification of design parameters not suitable for the local roadway environment. The study has highlighted multiple areas in the Namibian rural road safety system that urgently need to be addressed to provide a safer environment for road users on the network.

2. DATA

2.1 Study area

In the study by Ambunda (2021), in which the sensitivity assessment tools were developed, fatal and serious injury crash data was obtained for the Namibia national rural road network (see Figure 1). The national road network was divided into several classes (High Order Rural Roads (HORRs) and Low Order Rural Roads (LORRs)) (see Table 1) according to the functions of the roads and traffic volumes experienced on these roads using the Technical Recommendations for Highways on Road Classifications and Access Management (TRH 26) (Committee of State Road Authorities (CSRA), 1988). The national rural road network spans all fourteen regions in Namibia and is maintained by the Namibian Roads Authority, through subsidies provided by the Namibian Government and road user taxes and other fees collected by the Road Fund Administration (RFA) (Eggleston *et al.*, 2016).

Data on roadway design and conditions was provided by the Roads Authority of Namibia (RA). This data focused mainly on traffic volumes, speeds (operational, design and posted), road lane characteristics, road shoulder characteristics, road alignment, sight distances, access density and pavement conditions (Ambunda & Sinclair, 2022). The collection of roadway data also involved onsite data collection on the rural roads to supplement data sourced from the relevant authorities. A summary of the covariates used in the model development procedure is presented in Table 2. A total of 16 variables were included in the model development process, of which 14 were tested in the models (Ambunda & Sinclair, 2022). The covariates are divided into two groups of variable types, numerical and categorical covariates. Of these variables, nine of the variables relate to the geometric characteristics of the rural roadway system. Seven of the variables relate to the characteristics of the rural roadway, describing the traffic modal split, terrain and roadway surface types and conditions.

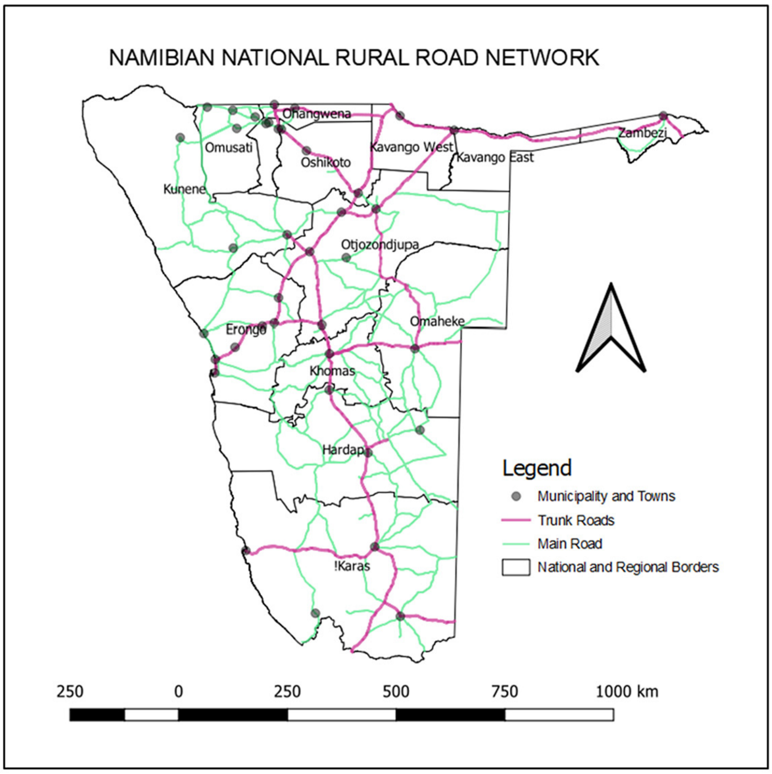

Figure 1: Namibian national rural road network (Ambunda, 2021; Ambunda & Sinclair, 2022)

Table 1: Functional classes of rural and urban roads TRH26 (CSRA, 1988)

Main class	Acronym	Rural Classes
High Order Rural Roads	R1	Rural principal arterial
	R2	Rural major arterial
	R3	Rural minor arterial
Low Order Rural Roads	R4	Rural collector road
	R5	Rural local road
	R6	Rural walkway

Table 2: Descriptive statistics of crash model covariates (Ambunda, 2021)

Descriptive statistic summary of covariates							
Covariate		**Min**	**Max**	**Mean**	**Std. Deviation**	**Variance**
Numerical Covariates	AADT_Light	85	14005	2328.44	2921.117	8532926.924
	AADT_Heavy	2	1400	345.29	376.970	142106.055
	AADT_Total	91	15362	2673.73	3231.762	10444282.947
	Operating_Speed (OS)	0	120	44.02	53.010	2810.020
	Lane_Width (LW)	2.940	12.450	5.156	2.552	6.513
	No_Lanes (NL)	1	6	1.79	.683	0.466
	Surface_SW (SSW)	0.000	3.175	0.255	0.562	0.316
	Ground_SW (GSW)	0.000	8.9900	1.713	0.652	0.425
	Horizontal_(Curves/Length) (Hor)	0.000	0.709	0.176	0.143	0.020
	Access_Density (AD)	0.000	0.409	0.121	0.086	0.007
	Section_Length (SL)	12.230	22.967	15.462	1.486	2.207
	SSD	15	2215	179.76	63.002	3969.274
Category Covariates	Surface type (SurT)	0	1	-	-	-
	Shoulder_type (ShoT)	0	1	-	-	-
	Terrain_Vertical (TV)	0	1	-	-	-
	Pavement_Condition	0	1	-	-	-

2.2 Crash Data

The study focused on fatal and serious injury crashes on trunk and main roads on the national rural road network. Hence, crash data was sourced from the Namibian National Road Safety Council (NRSC), Motor Vehicle Accident Fund of Namibia (MVA) together with Namibian police forms for the aforementioned road classes. The study analysis required reliable and accurate historical crash data, with information on traffic characteristics, traffic exposure variables and the road environment vital for an appropriate statistical analysis. The historical crash data collected from the Namibian road safety authorities was not geo-coded, with most of the site-specific crash information missing. As a result, it was important for the study to address the deficiencies in both the crash and roadway data (given in Section 2.1) by developing an approach to remove incomplete crash record data and by gathering additional site-specific information, to carry out a comprehensive statistical analysis focused on addressing road safety on national rural roads (Ambunda, 2021).

3. METHOD

The study applied the Generalised Linear Models (GLM) developed by Ambunda (2021) to assess the impact of existing and "ideal" road design characteristics on road safety. The mixed method approach involved the aggregation of design and traffic factors, and fatal and serious injury (FSI) to satisfy the mathematical form assumptions of the prediction models – namely (i) to generate logical results that do not cause the prediction of negative crash incidences and should ensure a prediction of zero crashes for zero values of exposure and length variables, and (ii) there must exist a known link function that can linearise the model form for the purpose of coefficient estimation (Ghanbari, 2017). The modelling approach was tested and validated using data from two datasets, representing FSI crashes on higher and lower-order rural roads. Through the use of data manipulation, it was possible to satisfy the assumptions of the GLMs and thus develop robust crash prediction models (CPMs). The study produced and compared the GLM CPMs using the Generalised Poisson models as the best-performing models.

The GLMs developed share several unique properties, such as linearity and a common method for parameter estimation that allows the development of effective CPMs for highways. The GLMs consist of the following three components (Oppong, 2012):

1. A random component, which specifies the conditional distribution of the response variable, Y_i given the exploratory variables, x_{ij}

2. A linear function of the regression variables, called the linear predictor, on which the expected value μ_i of Y_i depends.

$$Y_i = \propto + \beta_1 X_{i1} + \cdots + \beta_k X_{i1} = x'_i \beta \quad [1]$$

3. An invertible link function, $g(\mu_i) = \eta_i$ [2]

   The invertible link function transforms the expectation of the response to the linear predictor. The inverse of the link function is sometimes called the mean function:

$$g^{-1}(\eta_i) = \mu_i \quad [3]$$

The GLMs are an extension of the linear models to include response variables that follow any probability distribution in the exponential family of distributions (Eenink *et al.*, 2005; Field, 2013; Denis, 2021). Several measures were used to examine the validity of the models and how they fit the data in the study. These measures, presented in the study by Ambunda and Sinclair (2022), include the Scaled Deviance (SD), Pearson's Chi-Square (PCS), Akaike Information Criterion (AIC), Corrected Akaike Information Criterion (AICc) and Bayes Information Criterion (BIC).

4. RESULTS

The Impact of compliance of the national rural roads to the Technical Recommendations for Highways 17 on the Geometric Design of Rural Roads (TRH 17), the Technical Recommendations for Highways 20 on the Structural Design, Construction and Maintenance of Unpaved Roads (TRH 20) and Technical Recommendations for Highways 26 on Road Classification and Access Management (TRH 26) on the crash rates were tested to assess the sensitivity of the parameter estimates to the road characteristic changes. For that reason, two additional models were included in the study analysis. One model was developed to test the sensitivity on high-order rural roads (CPM 3), while the other model was developed to test the sensitivity of crash rates on low-order rural roads (CPM 4). The sensitivity analysis planned to test possible mediating effects of road design variables

The two additional models were developed using the Generalised Poisson Crash Predictive Modelling approach with reference to the 16 covariates tested in CPMs 1 and CPM 2 (parameters shown in Table 3 and Table 4, as CPM 1 and CPM 2, were determined in CPMs developed in a studies by Ambunda (2021) and Ambunda and Sinclair (2022)**,** to allow for a better basis for comparison of parameter estimates. All covariates in the GP-CPMs were adjusted to meet the TRH 17, TRH 20 and TRH 26 minimum requirements. The coefficient b* estimates for the statistically significant ($p<0.05$) covariates are demonstrated and compared in Table 3 (HORR) and Table 4 (LORR) in the sections below.

4.1 Impact of Design Compliance on High-Order Rural Roads

The estimates for the road design guidelines (TRH 17 and TRH 26) compliance sensitivity analysis of the crash prediction model (CPM) on high-order rural roads (HORR) are presented in Table 3. The crash prediction model tested with the compliant road design characteristics on HORRs (CPM 3) generated five (5) covariates with significant effects on the outcome variable, these being the proportion of heavy goods vehicles in AADT; the 85^{th} percentile speed, the lane width, the presence of vertical curves, and the ground shoulder width.

In the same way, the same number (5) of covariates demonstrated significant effects on crash rates on the CPM developed with existing road characteristics on HORRs (CPM 1). The CPM developed with compliant design characteristics (CPM $3_{adj\ R\text{-}sq.}$= 0.445) demonstrated an improved overall covariate combinatorial contribution to the variance observed compared to the CPM with existing rural road characteristics (CPM $1_{adj\ R\text{-}sq.}$= 0.421).

In the crash prediction model developed with existing road characteristics, the proportion of heavy vehicles in the AADT on the road section (CPM 1 b* = 0.682) reflected the highest absolute value of coefficient b*. The same covariate (heavy vehicles in AADT) also demonstrated the highest absolute coefficient b* value in CPM 2 (CPM 3 b* = -0.594). In contrast to the association with the crash rates demonstrated in CPM 1, the heavy traffic AADT covariate showed an opposite signed effect on HORR crash rates in CPM 3.

Two (2) of the covariates reflected an increased effect on the output variable after the design guideline compliance test, with reference to the estimated value of coefficient b*. These covariates are:

- The operating speed on HORRs (CPM 1 b* = 0.032 to CPM 3 b* = 0.041); and
- The vertical terrain on the HORRs (CPM 1 b* = 0.112 to CPM 3 b* = 0.120).

The sensitivity analysis results presented in Table 3 indicate that two covariates that statistically significantly influenced crash rates on HORRs, considering existing road characteristics, did not influence the outcome variable in the model developed with road design-compliant road characteristics. These covariates are:

- The lane width on high-order rural roads (CPM 1 b* = 0.137); and
- The ground shoulder width on high-order rural roads (CPM 1 b* = 0.108).

As a result of compliant road design characteristics, the proportion of paved shoulders (CPM 3 b* = 0.234) and the number of horizontal curves per rural road length (CPM 3 b* = -0.033) covariates demonstrated statistically significant effects on the crash rates on HORRs. This significant association is, however, absent in the model (CPM 1) tested using existing rural road characteristics on high-order roads.

Table 3: Sensitivity test on parameter estimates to road design guidelines (Comparing CPM 1-CPM 3)

Parameter	Parameter Estimate (Coefficient b*)	
	CPM 1 High Order Rural Roads (Existing Road Characteristics)	CPM 3 High Order Rural Roads (TRH 17 & TRH 26 Compliant Road Characteristics)
AADT_Heavy (AADTH)	0.682	-0.594
85^{th} Percentile Speed (Ops)	0.032	0.041
Lane Width (LW)	0.137	-
Surface_SW (SSW)	-	-
Terrain_Vertical (TV)	0.112	0.120
AADT_Light (AADTL)	-	-
No_Lanes (NL)	-	-
Surface_type (ST)	-	-
Shoulder_type (ShoT)	-	0.234
Ground_SW (GSW)	0.108	-
Horizontal (Curves/ length) (Hor)	-	-0.033
Access_Density (AD)	-	-
Pavement _Condition (PC)	-	-
SSD	-	-

4.2 Impact of Design Compliance on Low-Order Rural Roads

The sensitivity analysis of the crash prediction model (CPM) parameter estimates on low-order rural roads (LORR) to changes in compliance with TRH 17 and TRH 26 design guidelines is presented in Table 4. The crash prediction model for LORRs using design-compliant parameters (CMP $4_{adj\ R\text{-}sq.}$=0.386) demonstrated a markedly high improvement due to compliance, compared with the model with existing road characteristics (CPM $2_{adj\ R\text{-}sq.}$=0.159), as indicated by the adjusted R-square values of the respective models. In response to changes in design compliance, the crash prediction model developed for LORRs generated three (3) statistically significant covariates (CPM 4), compared to the four (4) significant covariates generated by the developed CPM 2 using the existing road characteristics.

The model results indicate that the proportion of light vehicles in the AADT (CPM 2 b* = 0.315) demonstrated the highest absolute influence (coefficient b* estimate) on the outcome variable in the LORR CPM 2. As a result of road characteristic compliance, the light vehicle AADT (CPM 4 b* = -0.204) covariate exhibited a reduced and opposite signed association to crash rates in CPM 4. On the other hand, the model results indicate that the ground shoulder width (CPM 2 b* = -0.205; CPM 4 b* = -0.412) covariate showed an increased coefficient b* estimate and exhibited the highest absolute influence on crash rates in CPM 4. In the same way, an increased influence on crash rates, though not statistically significant ($p>0.05$), is demonstrated by the vertical terrain (CPM 2 b* = 0.062; CPM 4 b* = 0.086) as a result of compliance with road design guidelines.

The model results also indicate that the operating speed (CPM 2 b* = 0.049) - which did not demonstrate a statistically significant coefficient estimate - and the surface shoulder width (CPM 2 b* = -0.138) covariates were not statistically significant in influencing the crash rates, as a consequence of compliant road characteristics to guidelines. In contrast (and counterintuitively), as a result of compliance with guidelines, the proportion of paved shoulder (CPM 4 b* = 0.241) and stopping sight distance (CPM 4 b* = 0.081) on LORRs demonstrated positive associations with crash rates. The paved shoulder significant association with crash rates was not recognised by the CPM developed for existing road characteristics on LORRs. Despite the stopping sight distance exhibiting some influence on the crash rates in CPM 4, it was however found to be statistically insignificant ($p>0.05$).

Table 4: Sensitivity test on parameter estimates to road design guidelines (Comparing CPM 2-CPM 4)

Parameter	Parameter Estimate (Coefficient b*)	
	CPM 2 Low Order Rural Roads (Existing Road Characteristics)	CPM 4 Low Order Rural Roads (TRH 17 & TRH 26 Compliant Road Characteristics)
AADT_Heavy (AADTH)	-	-
85th Percentile Speed (Ops)	0.049	-
Lane Width (LW)	-	-
Surface_SW (SSW)	-0.138	-
Terrain_Vertical (TV)	0.066	0.086
AADT_Light (AADTL)	0.315	-0.204
No_Lanes (NL)	-	-
Surface_type (ST)	-	-
Shoulder_type (ShoT)	-	0.241
Ground_SW (GSW)	-0.205	-0.412
Horizontal (Curves/ length) (Hor)	-	-
Access_Density (AD)	-	-
Pavement _Condition (PC)	-	-
SSD	-	0.081

5. DISCUSSION

The study investigated the sensitivity of the models (existing design characteristics) to the compliance of the design parameters to the TRH 17, TRH 20 and TRH 26. No local or international study exists examining the aspect of how road and traffic design fundamentals impact rural road safety. The novel findings from the sensitivity analysis are discussed in this section. A detailed analysis of the results on high-order rural roads (CPM 3) shows that the sensitivity test amplifies the influence of the operating speed and the vertical terrain – hilliness on FSI crash rates. The proportion of heavy vehicles in the traffic stream (CPM 1 $b^* = 0.682$ to CPM 3 $b^* = -0.594$) demonstrated a change in effect on road crashes. In contrast, the sensitivity test caused several of the direct-design parameters to lose effect (statistical significance) on road crash frequencies. These parameters are (1) the lane width and (2) the ground shoulder width. An increase in the proportion of paved shoulders on the higher order roads was observed to cause an increase in road crash rates, due to design compliance. This result is somewhat surprising as the compliance test on the high-order roads indicates that the majority of these roads do not have the appropriate shoulder types to accommodate the observed high traffic volumes and expected high traffic speed selections by drivers. Several factors could explain this correlation between shoulder types and crashes. An increase in the proportion of a paved shoulder combined with wider lane widths may result in perceived space to correct errors and thus higher speed selections and in-lane deviations. In reality, however, this increases the risk of run-off crashes. Also, drivers may decide to use the hard-paved shoulder as an "extra" lane to give space to vehicles making overtaking manoeuvres in the traffic stream (fairly common driver behaviour in southern Africa). This practice can present dangerous situations for other drivers, especially when combined with factors such as night-time driving, non-compliant ground shoulder widths and high traffic speeds. Several studies have investigated the impact of present shoulder types on road sections, without delving into whether the appropriate shoulder type is provided (Stamatiadis *et al.*, 2009; Sisiopiku, 2011; Ambunda & Sinclair, 2019).

The sensitivity test results on higher-order roads indicated that increasing the extent of bendiness (also somewhat surprisingly) resulted in a decrease in the frequency of road crashes. In the local context, conditions are such that long straight sections in monotonous road environments are prevalent on the road network (Adanu *et al.*, 2020; Ambunda & Johannes, 2020). These sections can predispose rural road drivers to fatigue-related crashes. Fatigue can affect driving skills by increasing the frequency, amplitude and variability of errors (Dagli, 2004; Bener *et al.*, 2017). Therefore, the model findings explain that increasing the bendiness may indirectly lead to an increase in the level of driver engagement in the driving process, thus, reducing road crashes due to monotonous environment-related fatigue.

The sensitivity test on low-order rural roads (CPM 4) showed a significant impact on the effect that the surfaced shoulder width and the hilliness of the vertical alignment have on crash occurrence. Due to the combined effects of design-compliant parameters, both parameters lost their statistically significant influence on crash frequency. The proportion of light vehicles demonstrated a change in effect while the ground shoulder width on the road sections demonstrated an increased absolute effect on crash frequency. Similarly for CPM 3, an ideal design environment on lower-order roads resulted in the proportion of paved hard-shoulders demonstrating a statistically significant positive association to crash rates. The stopping sight distance (SSD) was found to exhibit "some" influence in the sensitivity test, though statistically insignificant. The statistical insignificance of the SSD is expected due to the road environment on the rural road network – mostly flat terrains and long road sections with high levels of forward visibility.

6. CONCLUSIONS AND RECOMMENDATION

Inherently, roads designed according to accepted design principles should mitigate the potential risk that other road users could pose by offering a physical environment capable of tolerating some degree of error. Design principles also enable road characteristics to play a clear role in guiding drivers of all categories as to the type and function of the road, as well as informing them about the level of risk that they should prepare for. Road designs need to create the right impressions to solicit appropriate behaviour from all drivers – design and planning authorities should therefore consider spatial knowledge, the skills and awareness of road users that develop overtime – facilitate the development of skills, hazard and risk perception, among other things, manoeuvring in relation to the road characteristics, estimation of vehicle speeds and the ability to judge and accept gaps.

With this in mind, the novel GP CPMs developed were used to carry out a sensitivity analysis using the design standards that were applied in the design of most of the national rural roads, to test how the model parameters would react to potential remedial design measures and indirectly test the level of safety incorporated into the design principles. The insights from the sensitivity analysis were concerning, and pointed towards the application of remedial measures on the rural roads and revision of some of the design principles used. Also, it is important to note that the capacity of some of the roads has been far exceeded over the years. This emphasises the urgency to audit some of these roads and apply findings from the study towards developing a safe system for current and future road users. In summary, the novel CPMs provide a crucial opportunity and step towards building a crash risk control system that embraces all crash risk factors throughout the lifecycle stages of the roads.

7. DECLARATION OF COMPETING INTERESTS

The authors declare no conflict of interest. This study received no external funding.

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9. REFERENCES

AASHTO. 2011. *A Policy on Geometric Design of Highways and Streets*. Fouth. Washignton D.C: AASHTO.

Abele, L & Møller, M. 2011. The Relationship between Road Design and Driving Behavior, *RSS 2011: Road Safety and Simulation 2011 Conference*, 2012:1-16. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:THE+RELATIONSHIP+BETWEEN+ROAD+DESIGN+AND+DRIVING+BEHAVIOR#1%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+Relationship+between+Road+Design+and+Driving+Behavior%231.

Adanu, EK, Jones, S & Odero, K, 2020. Identification of factors associated with road crashes among functionally classified transport modes in Namibia, *Scientific African*. Elsevier B.V., 7, p. e00312. Doi: 10.1016/j.sciaf.2020.e00312.

Agerholm, N, Knudsen, D & Variyeswaran, K, 2017. Speed-calming measures and their effect on driving speed – Test of a new technique measuring speeds based on GNSS data, *Transportation Research Part F: Traffic Psychology and Behaviour*. Elsevier Ltd, 46:263-270. Doi: 10.1016/j.trf.2016.06.022.

Ambunda, R. 2021. *Developing road crash prediction models to investigate the combination of effects of roadway conditions on national rural road crashes*. Stellenbosch University. Available at: https://scholar.sun.ac.za/items/d621ff99-0b00-42c0-8729-db9ce2493285.

Ambunda, R & Johannes, P. 2020. Assessment of the Impact of Namibian Rural Road Characteristics on Crash Incidence, *Athens Journal of Technology and Engineering*, 7(1):15-30.

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.

Ambunda, R & Sinclair, M. 2022. Traffic safety and the rural road environment: Assessing the impact of combined roadway conditions on crash incidence, *Journal of the South African Institution of Civil Engineering*, 64(4):38-48. Doi: 10.17159/2309-8775/2022/v64n4a4.

Bener, A, Yildirim, E & Lajunen, T. 2017. Driver sleepiness, fatigue, careless behavior and risk of motor vehicle crash and injury Population based case and control study . *Journal for Traffic and Transportation Engineering*, 4(5):496-502. Doi: 10.1016/j.jtte.2017.07.005.

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

Committee of State Road Authorities. 1988b. Road Classification and Access Management, in *Technical Recommendations for Highways, TRH 26*. Pretoria, South Africa: Department of Transport.

Dagli, R. 2004. Driver fatigue and Road safety - Implcation in an indian context', *International journal of advances in Engineering and Tehnology*, 9(4):1-5.

Denis, D. 2021. Multiple Linear Regression, in *Applied Univariate, Bivariate, and Multivariate Statistics*, pp. 232-285. Doi: 10.1002/9781119583004.ch7.

Eenink, R *et al.* 2005. Accident Prediction Models and Road Safety Impact Assessment: Recommendations for using these tools, *RiPCORD iSEREST*, 506184 (January 2005), pp. 1-20.

Eggleston, Z, Hansen, P & Carrera, F. 2016. Improvement of Road Safety: Route - based Assessment on Major Roads in Namibia.

Field, A. 2013. *Discovering Statistics using IBM SPSS Statistics*. 4th edn, *British Library Cataloguing*. 4th edn. London: SAGE Publications Inc.

Ghanbari, A. 2017. *Impact of Pavement Condition Indicators on Road Safety in New Brunswick Arash Bagher Ghanbari Master of Science in Engineering*. University of New Brunswick.

Khayesi, M & Peden, M. 2005. Road safety in Africa, *British Medical Journal*, 331(7519):710-711. Doi: 10.1136/bmj.331.7519.710.

Kopits, E & Cropper, M. 2005. Traffic fatalities and economic growth, *Accident Analysis and Prevention*, 37(1):169-178. Doi: 10.1016/j.aap.2004.04.006.

Mitra, S *et al.* 2021. *Guide to Integrating Safety into Road Design*. Washignton D.C. Available at: http://www.worldbank.org/transport.

Oppong, RA. 2012. Statistical Analysis of Road Accidents Fatality in Ghana Using Poisson Regression, *Thesis submitted to the Department of Mathematics, Kwame Nkrumah University of Science and Technology*, p. 80.

Padmanaban, J *et al.* 2010. Analysis of in-depth crash data on Indian national highways and impact of road design on crashes and injury severity, *Berichte Der Bundesanstalt Fuer Strassenwesen. Unterreihe Fahrzeugtechnik*, (77).

Pinard, MI, Ellis, SD & Eriksson, CH, 2003. *SADC Guideline on Low- Volume Sealed Roads*. Goldfields Press (Pty) Ltd.

Semar, H. 2003. *Design Manual for Roads and Bridges*. 6th edn, *Roads Directorate*. 6th edn. Floriana: Malta Transport Authority. Doi: 10.1034/j.1600-0846.2003.00019.x.

Sisiopiku, VP. 2011. Crash prediction on rural roads, pp. 1-14.

Slop, M. 1994. Safety effects of road design standards, *International conference, Road safety in Europe and Strategic Highway Research Program*, (September), pp. 26-28.

Stamatiadis, N *et al.*, 2009. *Impact of Shoulder Width and Median Width on Safety*, *Impact of Shoulder Width and Median Width on Safety*. Doi: 10.17226/14252.

Thomas, L *et al.* 2013. *Speed and Safety in North Carolina*. Available at: https://connect.ncdot.gov/projects/research/RNAProjDocs/2011-08finalreport.pdf%0Ahttps://trid.trb.org/view/1277053.

Weller, G *et al.* 2008. Behaviourally relevant road categorisation: A step towards self - explaining rural roads, *Accident Analysis & Prevention*, 40:1581-1588. April. Doi: 10.1016/j.aap.2008.04.009.