International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-4, February 2019

Effect of Two-Lane Two-Way Rural Roadway Design Elements on Road Safety

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Abstract*: Road design elements are some of the key factors influencing road user behaviour and road safety on roads worldwide. The study developed fatal crash predictive Negative Binomial Regression (NBR) models that identified statistically significant relationships between the combination of road design elements (radii and number of horizontal curves, hard shoulder widths, traffic operating speeds, road length and access control) selected for the study and the fatal crashes rates on the selected roads on the Namibian rural road network. The crash predictive NBR models developed indicated that the combination of the various selected road design elements had significant influence on the fatal crash rates, with various correlation magnitudes on roads with various lane widths. The study results brought to the fore the impact that interactions between selected road design elements has on existing road design and maintenance methods in Namibia. The NBR fatal crash models will assist transportation engineers in identifying hazardous road sections and implementing the appropriate remedial measures to reduce crash risk levels sustainably.

Key words: Crash modelling; fatal crashes; negative binomial regression; road design elements; road safety

I. INTRODUCTION

Over the past twenty years up until 2018, road crash modelling has attracted great research interest in identifying statistically significant relationships between road design characteristics and the crash rates on the roadways, due to its vital practicality and wide range of applications.

Road crash modelling can be useful for identifying road sections prone to a high frequency of road crashes and high injury severities, while determining the factors significantly influencing the occurrence of road crashes. Information on the factors significantly influencing the occurrence of road crashes is vital for transportation authorities to identify appropriate remedial measures to combat and reduce crash injury severities on the roadway. A combination of various factors shown in Figure 1 influences the occurrence of road crashes.

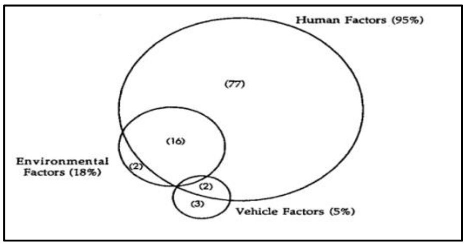

Fig. 1: Contributing factors to road crashes

Traffic safety can be influenced by improving the geometrical aspects of the roadway system, together with developing and enforcing traffic rules, and educating road users on the importance of road safety (Čičković, 2016). Several studies have shown that improvements to the design of the roads can significantly reduce the frequency of road crashes (Gaudry and Vernier, 2002; Deller, 2013; Jaiswal and Bhatore, 2016).

This paper examined the relationship between the fatal crash rates and rural roadway geometry on the most hazardous roads in Namibia, using a thorough parametric statistical modelling technique known as Negative Binomial Regression (NBR). The main goal of this paper was to develop a quantitative and mathematically sound method that assesses the significance of the relationship between rural roadway geometry and fatal crash rates.

II. BACKGROUND

Traffic safety is a major concern in developing countries. The road system encompasses the road users, vehicles operated on the roads and the road environment within which they operate (Krug and Sharma, 2009). Karlaftis and Golias (2009) report that the safety of the roadway is dependant on the interplay of several key factors, among which is the ability of the roadway geometry to communicate crucial information to drivers, to enable drivers to adopt and adjust their driving accordingly without compromising their safety and the safety of all road users. Several studies have shown that road geometry affects drivers' behaviour and has a significant impact on fatal crash rates (Woolley et al., 2002; Porter et al., 2012; Othman and Thomson, 2007).

The combination of various roadway design elements can have a significant impact on drivers' perceptions and behaviour (Dwikat, 2014). One of the key road safety risk factors affected by drivers' perceptions of road safety is driving speed. Driver speed selections are based almost exclusively on information communicated by road design elements.

Manuscript published on 28 February 2019.
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More, where vertical and horizontal curves overlap, a reduction in sight distances is observed and erroneous driver perceptions are evident (Hagenzieker et al., 2014). The combination of a crest vertical curve and horizontal curve results in drivers selecting lower speeds, as drivers mostly perceive these curves to be less sharp (Easa et al., 2007). Garcia and Abreu (2016) indicated that the curvature of the roadway significantly impacts drivers' perceptions of risk. Thus, straight roads are perceived as less risky despite the risks of driver fatigue on lengthy straight road sections.

Vayalamkuzhi and Amirthalingam (2016) study on geometric characteristics indicated that road design variables and combinations of some of the variables have a significant impact on traffic safety on the roads. The radii of horizontal curves were found to have a statistically significant impact on traffic safety, while estimating the 85th percentile operating speed on two-lane two-way rural roadways (Taylor et al., 2000).

Researchers have found that road characteristics such as lane widths, shoulder widths, access control and average annual daily traffic (AADT) contribute to the frequency of fatal crashes (Dwikat, 2014; Garber and Hoel, 2009; Persia et al., 2016). Road sections with high AADT, more road lanes and higher posted speed limits were identified as having higher road crash rates and higher injury severities (Karlaftis and Golias, 2002).

Several studies have shown that wider road and lane widths have a negative effect on driver behaviour (Dwikat, 2014; Iyinam et al., 1997; Ahmed, 2013). Drivers' speed selections and fatal crash rates are higher on wider road and lane widths, compared with lower speed selections and fatal crash rates on narrow road and lane widths (Deller, 2013). Narrow shoulder widths were found to be associated with negative driving behaviour on road sections (Dehuri, 2013). Ben-Bassat and Shinar (2011) found that due to visual cues that indicate narrow lane widths on roads with narrow shoulder widths, drivers tend to steer away from the hard shoulders and drive close to the centre of the road, increasing the chances of being involved in a head on collision. Higher speed selections were observed on wider hard shoulders and lane widths as drivers' perceived a sense of security and chances to correct driver errors should they occur (Mohammed, 2013).

The use of multiple linear regression in road crash modelling suffers from repeated practical inconsistencies and logical limitations, due to the random nature and occurrence of fatal crashes. Several studies have overcome these shortcomings by using Poisson Regression models, which is a good alternative for events that occur independently and randomly over time (Taylor et al., 2000; Mohammed, 2013). The restrictions with Poisson Regression is that it assumes that the variance and mean of the dependant variable are equal. This condition, when violated, invalidates the t-test parameter estimates (Gaudry and Vernier, 2002). Negative Binomial Regression (NBR) models overcome this limitation by allowing for the variance of the dependant variable to be greater than the mean (Vayalamkuzhi and Amirthalingam, 2016). Therefore, NBR models are instrumental in analysing the safety of roadways by identifying relationships between road crashes and road characteristics.

In this paper, ten locations with the highest fatal crash rates on the Namibian rural road network were identified for the study. The historical crash databases, road traffic data and geometric characteristics of the study sections were used to develop predictive crash models for the study locations.

III. DATA AND METHOD

3.1 Data

Information from three existing rural road databases for the period 2013 to 2016 were used for the study. Road crash and injury severity data was obtained from the Motor Vehicle Accident (MVA) Fund of Namibia and the National Road Safety Council (NRSC) of Namibia. Rural road geometric and traffic information was sourced from the Roads Authority (RA) of Namibia.

To prevent inconsistencies arising in the data and the analysis, two-lane two-way rural roadways that had remedial geometric work or geometric upgrades during the study period 2013 to 2016 were excluded from the NBR analysis. Table 1 shows the road design variables selected for the study, on which adequate information was provided by the RA of Namibia for the NBR analysis.

Table 1: Road Design Variables used in the NBR Analysis

Road Variable	Units	Variable Description
Annual Average Daily Traffic (AADT)	Total Veh/ 365 days	Total volume of vehicles using a study section per year
85th Percentile Operating Speed	Km/ hour	Speed at/ below which 85% of the drivers operate
Number of lanes	Count	The number of dedicated roadway portions for a single line of vehicles to travel.
Lane width	Metres	The width of the road portion dedicated for a single line of vehicles.
Shoulder width	Metres	The width of the roadway portion adjacent to the travelling lanes
Access Control	Count	The number of access points available for drivers to access road adjacent land uses.
Horizontal Curves	Degree	Curves that facilitate a smooth transition when drivers change direction on the road.
Section Length	km	The length of the rural road section traversed by vehicles

3.2 Method

Existing road fatal crash and road geometric information databases were used to develop predictive crash models and analyse the relationship between fatal crashes and road

geometric characteristics for the study period 2013 to 2016.

Two-lane two-way rural road sections with the highest fatal crash rates were identified from the Namibian road network as shown in Table 2.

Figure 2 shows the fatal crash frequency on the Namibian rural road network over the study period 2013 to 2016. Joanne (2013) recommended an average minimum threshold of 5kms on the single carriageways from an urban environment as a starting point for the crash risk level assessment on rural roads. Road sections with fewer than 20 fatal crashes over the three-year study period were not considered for the NBR analysis, as the variation in the frequency of fatal crashes can become too large.

Table 2: Ten Worst Rural Roads in Namibia (2013-2016)

No.	Road Segment	Road Length(km)	No. of Fatal Crashes	Fatal Crashes/ Km	Crash Rates [i]
1	T0112	35.80	50	0.84	***0.22***
2	M0092	24.80	20	0.81	***0.06***
3	T1002_1	36.61	26	0.71	***0.29***
4	T0106	64.42	39	0.61	***0.03***
5	T0111_1	92.26	53	0.57	***0.27***
6	T0111_2	61.82	33	0.53	***0.12***
7	T0105	73.58	34	0.46	***0.07***
8	T1002_2	99.75	39	0.39	***0.21***
9	T0107	164.60	62	0.38	***0.13***
10	T0110	84.95	29	0.34	***0.24***

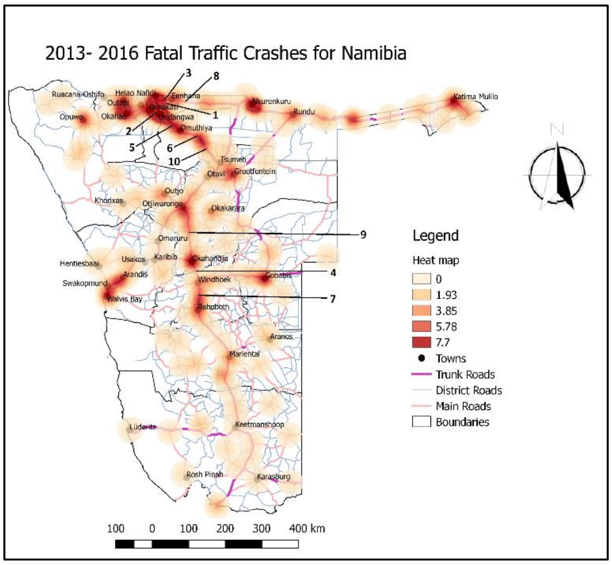

Fig. 2: Fatal Crashes Distribution on the Namibian Rural Road Network (2013-2016)

The study used a parametric data analysis methodology known as Negative Binomial Regression, shown in Equation (1) that allows for the variance of the dependant variable to be greater than the mean. NBR was used to develop predictive crash models and analyse the relationship between fatal road crashes and road design variables in the study.

$$\ln \cdot = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \qquad (1)$$

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

In NBR, the probability value (p-value) determined by the F-test performed indicated the significance of the relationship between fatal crash rates and the road design variables selected for the predictive crash models. The strength of the relationship indicated by the correlation coefficient R2 was considered statistically significant if the p-value was equal to 0 up to 5 percent difference from zero.

IV. RESULTS AND DISCUSSION

The effects of the interaction of selected road design variables on the fatal crash rates were analysed using the predictive Negative Binomial Regression (NBR) models developed. Using lane widths as the main split criteria in the analysis, the covariate effects on road sections with lane widths greater than 3.5m were compared with the effects on road sections with lane widths equal to or less than 3.5m. The combination of all the covariates (Road length, lane width, number of horizontal curves, radii of the horizontal curves, hard shoulder width, 85th percentile speed and access control) on the road sections was found to have a statistically significant effect on fatal crash rates on all the study sections, as the p-values were less than the statistical alpha value of 0.05.

4.1 Lane widths > 3.5m road sections

The NBR model for the combination of all covariates on road sections with lane widths greater than 3.5m, statistically significantly (p value= 0.000 • 0.05) accounted for 95.04% of the variance in the fatal crash rates. The combination of all covariates' results showed that the 85th percentile speed had a statistically significant positive correlation (p value= 0.000< 0.05; B= 0.350) with fatal crash rates, while lane widths had a statistically significant negative correlation (p value= 0.039< 0.05; B= -3.208) with fatal crash rates.

The combination of lane widths and hard shoulder widths was statistically significantly (p value= 0.000< 0.05) accounting for 84.05% of the variance in the fatal crash rates, with the NBR model showing significant negative correlation (p value= 0.000< 0.05; B= -15.4229) between hard shoulder widths and fatal crash rates.

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The NBR model results showed that lane widths, together with the horizontal curve radii and the 85th percentile speeds, statistically significantly (p value= 0.000< 0.05) accounted for 95.32% of the variance in the fatal crash rates, with a statistically significant negative correlation indicated by the horizontal curves radii (p value= 0.007< 0.05; B= -0.003) and the lane widths (p value= 0.025< 0.05; B= -3.254), while the 85th percentile speeds (p value= 0.000< 0.05; B= 0.341) showed a positive correlation.

Results further showed that the combination of the horizontal curves radii and the number of horizontal curves on the study section was statistically significantly (p value= 0.000< 0.05) influencing fatal crash rates, accounting for 85.26% of the variance in the fatal crash rates The number of horizontal curves exhibited a significant positive correlation (p value= 0.03< 0.05; B= 0.2955) with fatal crash rates, while the radii of the horizontal curves indicated a significant negative correlation (p value= 0.0012< 0.05; B= -0.0071).

The results indicated that the combination of access control and road length on the road sections with lane widths greater than 3.5m had a statistically significant (p value= 0.0024< 0.05) influence on the fatal crash rates, accounting for 41.46% of the variance in fatal crash rates. The level of access control had a significant positive correlation (p value= 0.0006< 0.05; B=0.9993) with fatal crash rates on the road sections. Table 3 shows the relationships and correlations found by the developed crash predictive NBR models for sections with lane widths greater than 3.5m.

Table 3: NBR Models Information on Roads with Lane Widths Greater than 3.5m

Road Variables Combinations	Statistically Significant Variable	Variable P Value	Variable B value	Model P value	Model Adjusted R^2
All Covariates	Speed	0.0000	0.350	0.000	0.9504
	LW	0.0390	-3.208		
LW [ii]& SW [iii]	GSW	0.0000	-15.4229	0.000	0.8405
LW, HCRAD [iv]&OpSpeed[v]	LW	0.0250	-3.254	0.000	0.9532
	HCRAD	0.0070	-0.003		
	OpSpeed	0.0000	0.341		
HCNUM [vi]& HCRAD	HCNUM	0.0300	0.2955	0.000	0.8526
	HCRAD	0.0012	-0.0071		
AC [vii]& Length	AC	0.0006	0.9993	0.0024	0.4146

[1] LW represents the Lane Width
[1]SW represents the Shoulder Width
[1]HCRAD represents the Radii of the Horizontal Curves
[1]OpSpeed represents the 85[th] percentile speed
[1]HCNUM represents the Number of Horizontal Curves
[1]AC represents the access control on the road sections

4.2 Lane widths ≤ 3.5m road sections

Statistical analysis using NBR models showed that the combination of all covariates had a statistically significant (p value= 0.0012< 0.05) influence on the fatal crash rates on road sections with lane widths equal to or less than 3.5m, with the model accounting for 68.69% of the variance in fatal crash rates. On road sections where all covariates were combined, the lane width had a significant negative influence (p value= 0.001< 0.05; B= -17.961) on the fatal crash rates.

Results showed that the combination of lane widths, horizontal curves radii and hard shoulder widths significantly (p value= 0.000) accounted for 75.15% of the variance in fatal crash rates on the road sections, with the lane widths (p value= 0.000< 0.05; B= -18.3834) and hard shoulder widths (p value= 0.007< 0.05; B= -1.4680) having a significant negative influence on the fatal crash rates.

The combinations of access control and road length on road sections had a significant influence (p value= 0.033< 0.05) on the fatal crash rates, accounting for 19.76% of the variance in fatal crash rates. The NBR model results indicated that despite the combination of the two covariates significantly influencing fatal crash rates, the access control individually in the NBR model had a significant positive influence (p value= 0.011< 0.05; B= 1.0277) on the fatal crash rates.

The NBR model showed that the number of horizontal curves combined with the road length significantly influenced (p value= 0.017< 0.05) the fatal crash rates on sections with lane widths equal to or less than 3.5m, accounting for a low 24.75% of the variance in the fatal crash rates. The road length (p value= 0.024< 0.05; B= 0.1999) and number of horizontal curves (p value= 0.004< 0.05; B= 0.4863) were indicated by the NBR model to have a significantly low positive correlation with fatal crash rates on the road sections. Table 4 provides information on the developed crash predictive NBR models for study road sections with lane widths equal to or less than 3.5m.

Table 4: NBR Models Information on Roads with Lane Widths Equal to or less than 3.5m

Road Variables Combination	Statistically Significant variables	Variable P Value	Variable B Value	Model P Value	Model Adjusted R^2
All Covariates	LW	0.001	-17.961	0.0012	0.6869

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LW, HCRAD and SW	**LW**	**0.000**	**-18.3834**	**0.000**	**0.7515**
	GSW	0.007	-1.4680		
AC & Length	AC	0.011	1.0277	0.033	0.1976
HCNUM & Length	HCNUM	0.004	0.4863	0.017	0.2475
	Length	0.024	0.1999		

V. CONCLUSIONS

The study developed crash predictive Negative Binomial Regression models and examined the effects of road design variables on the safety of the roadways.

The crash predictive NBR models developed showed that certain combinations of road design variables on the road sections were statistically significant in influencing the crash risk level on the study sections.

On roads with lane widths greater than 3.5m, the lane widths and 85th percentile speeds were found to significantly influence the fatal crash rates when combined with all the covariates in the study. The NBR model indicated that a high significant correlation exists between the fatal crash rates and all the covariates on the road study sections.

The interaction between lane widths and shoulder widths had a high significant correlation with fatal crash rates, with shoulder widths significantly influencing the frequency of fatal crashes on the road sections. Several studies (Karlaftis and Golias, 2009; Abele and Møller, 2011) have indicated that hard shoulder widths have an effect on the visual cues received by drivers. Narrow shoulder widths make the road lanes seem narrow, while wider shoulder widths make the road lanes seem wider, therefore impacting drivers speed selections on the road sections.

The interaction between the lane widths, radii of horizontal curves and the 85th percentile speeds on roads with lane widths greater than 3.5m influenced fatal crash rates with a high significant correlation. Increasing the lane width by one unit significantly reduced the log count of fatal crash rates on the study road sections. Previous studies (Dwikat, 2014; Gaudry and Vernier, 2002) found lane widths to have a significant impact on fatal crash rates, even though it was examined separately from other road design variables.

On road sections with lane widths greater than 3.5m, the combination of the radii and number of horizontal curves had a significantly high correlation with fatal crash rates. Several studies (Iyinam et al., 1997; Mohammed, 2013) have indicated that the drivers' speed selection on horizontal curves are lower in comparison to other road design elements, despite a high frequency of fatal crashes on horizontal curves.

The interaction of access control and the road length on the road sections had a significantly low correlation with fatal crash rates. Even though the combination of the two predictors was statistically significant, only the access control predictor significantly influenced the fatal crash rates in the crash predictive NBR models. In contrast, a previous study by Alsubeai (2017) showed that access control had a significant and high correlation impact on fatal crash rates, when combined with traffic volumes on the road sections.

On road sections with lane widths equal to or less than 3.5m, the interaction between all the covariates in the study had a significant correlation with fatal crash rates on the sections, with the NBR model indicating that the lane widths predictor had a significant impact on fatal crash rates. A one-unit increase in the lane widths resulted in a considerable decrease in the frequency of fatal crashes.

The interaction between the lane widths, shoulder widths and the radii of the horizontal curves had a significantly high correlation with fatal crash rates on road sections with lane widths equal to or less than 3.5m. The NBR model showed that lane widths and ground shoulder widths predictors individually had a significant influence on fatal crash rates on the road sections. More interestingly, the radii of horizontal curves did not have a significant impact on fatal crash rates in the NBR model. Previous studies (Yingxue, 2009; Porter et al., 2012) that examined the effect of horizontal curves radii on fatal crash frequencies, indicated that it played a key role in driver behaviour, expressed through speed selections and fatal crash rates on the road sections.

The combination of the access control and road length on road sections with lane widths equal to or less than 3.5m had a significantly low correlation with fatal crash rates on the road sections, with the access control individually having a significant influence on fatal crash rates.

Less obvious and more surprising, the NBR models showed that the interaction between the number of horizontal curves and the length of the road sections significantly influenced fatal crash rates, despite the low correlation.

The study findings demonstrated that road design elements have more significant correlations on roads with lane widths greater than 3.5m than on those with lane widths equal to or less than 3.5m. The study indicated that the radii of the horizontal curves and the 85th percentile speeds predictors were individually significant in the NBR models in influencing fatal crash rates, on road sections with lane widths greater than 3.5m. The results indicated that the interaction between selected road design variables plays a key role in influencing fatal crash rates on the road sections.

The study findings have demonstrated that alternative road design methods that take into account the impact of the interaction of road design variables on crash risk levels should be investigated and considered for development.

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ACKNOWLEDGEMENT

Enormous gratitude goes to the study leader, Prof. Marion Sinclair, for the valuable support, guidance and mentorship provided throughout the study.

REFERENCES

1. Abele, L. and Møller, M. (2011) 'The Relationship between Road Design and Driving Behavior', RSS 2011: Road Safety and Simulation 2011 Conference, 2012, pp. 1–16. Available from: 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#1. (Accessed: 10 November 2017).
2. Ahmed, I. (2013) 'Road Infrastructure and Road Safety', Transport and Communications Bulletin for Asia and the Pacific, (83), pp. 19–25.
3. Alsubeai, A. M. (2017) Evaluating the Interactive Effects of Traffic Volumes and Access Density on Crash Frequency. South Dakota State University.
4. Ben-Bassat, T. and Shinar, D. (2011) 'Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior', Accident Analysis and Prevention. Elsevier Ltd, 43(6), pp. 2142–2152. Available from: doi: 10.1016/j.aap.2011.06.004. (Accessed: 24 July 2018).
5. Čičković, M. (2016) 'Influence of Human Behaviour on Geometric Road Design', Transportation Research Procedia, 14(0), pp. 4364–4373. Available from: doi: 10.1016/j.trpro.2016.05.358. (Accessed: 12 May 2017).
6. Dehuri, A. N. (2013) Impacts of Roadway Condition , Traffic and Manmade Features on Road Safety, Asian Journal of Civil and Road Engineering. India National Institute of Technology.
7. Deller, J. (2013) 'The influence of road design speed, posted speed limits and lane widths on speed selection: a literature synthesis', in Australasian Transport Research Forum, p. 14p. Available from: http://www.atrf.info/papers/2013/index.aspx. (Accessed: 06 June 2017).
8. Dwikat, M. G. (2014) Modeling Relationship between Geometric Design Consistency and Road Safety for Two-Lane Rural Highways in the West Bank. An- Najah National University.
9. Easa, S. M., Dong, H. and Li, J. (2007) 'Use of Satellite Imagery for Establishing Road Horizontal Alignments', Journal of Surveying Engineering, 133(1), pp. 29–35. Available from: doi: 10.1061/(ASCE)0733-9453(2007)133:1(29). (Accessed: 19 May 2017).
10. Garber, N. J. and Hoel, L. a (2009) Traffic and Highway Engineering. Fourth, Cengage Learning. Fourth. Edited by H. Gowans. Toronto, Canada: Nelson Education Ltd. Available from: doi: 10.1061/(ASCE)HY.1943-7900.0000746 (Accessed: 11 August 2017).
11. Garcia, R. and Abreu, L. (2016) 'Road safety in rural roads of two lanes', RevistaIngenieria De Construccion, 31(1), pp. 54–60.
12. Gaudry, M. and Vernier, K. (2002) 'Effects of road geometry and surface on speed and safety', Accident Analysis & Prevention 34.3, 34(November 2002), pp. 357–365.
13. Hagenzieker, M. P., Commandeur, J. J. F. and Bijleveld, F. D. (2014) 'The history of road safety research: A quantitative approach', Transportation Research Part F: Traffic Psychology and Behaviour. Elsevier Ltd, 25(PART B), pp. 150–162. Available from: doi: 10.1016/j.trf.2013.10.004. (Accessed: 22 March 2018).
14. Iyinam, A., Iyinam, S. and Ergun, M. (1997) 'Analysis of relationship between highway safety and road geometric design elements: Turkish case', Faculty of Civil Engineering, Turkey. Available from: http://www.trafficforum.ethz.ch/vwt_2003/beitraege/vwt19proceedings_contribution_91.1-91.8.pdf. (Accessed: 09 November 2017).
15. Jaiswal, A. and Bhatore, A. (2016) 'Effect on Road Safety by Roadway condition, traffic and manmade features', International Journal of Latest Trends in Engineering and Technology, 7(3), pp. 41–48. Available from: doi: 10.21172/1.73.006. (Accessed: 14 July 2018).
16. Joanne, M. (2013) RAP Road Risk Mapping Manual : Design Specification.
17. Karlaftis, M. G. and Golias, I. (2002) 'Effects of Road Geometry and Traffic Volumes on Rural Roadway Accident Rates', Accident Analysis and Prevention, 34(3), pp. 357–365. Available from: doi: 10.1016/S0001-4575(01)00033-1. (Accessed: 21 November 2017).
18. Karlaftis, M. G. and Golias, I. (2009) 'Impacts of Roadway Condition , Traffic and Manmade Features on Road Safety', International Journal of Civil Engineering & Technology, 4(July), pp. 19–25. Available from: doi: 10.1061/(ASCE)HY.1943-7900.0000746. (Accessed: 17 September 2017).
19. Krug, E. and Sharma, G. (2009) 'Risk factors for road traffic injuries', AsociatiaVictimelorAccidentelor de Circulatie din Romania, 7(2), pp. 23–39.
20. Mohammed, H. (2013) 'The Influence of Road Geometric Design Elements on Highway Safety', International Journal of Civil Engineering & Technology, 4(4), pp. 146–162.
21. Othman, S. and Thomson, R. (2007) 'Influence of Road Characteristics on Traffic Safety', in ESV 20th Conference. Lyon, pp. 1–10.
22. Persia, L., Usami, D., De Simone, F. and Yannis, G. (2016) 'Management of Road Infrastructure Safety', Transportation Research Procedia. Elsevier B.V., 14, pp. 3436–3445. Available from: doi: 10.1016/j.trpro.2016.05.303. (Accessed: 13 June 2018).
23. Porter, R., Donnell, E. and Mason, J. (2012) 'Geometric Design, Speed, and Safety', Transportation Research Record: Journal of the Transportation Research Board, 2309, pp. 39–47. Available from: doi: 10.3141/2309-05. (Accessed: 15 June 2017).
24. Taylor, M. C., Lynam, D. A. and Baruya, A. (2000) 'The effect of drivers' speed on the frequency of road accidents', Transportation Research Laboratory, p. 56. Available from: doi: 10.1051/ matecconf 2016 00 / 47 3 04. (Accessed: 16 November 2017).
25. Vayalamkuzhi, P. and Amirthalingam, V. (2016) 'Influence of geometric design characteristics on safety under heterogeneous traffic flow', Journal of Traffic and Transportation Engineering (English Edition). Elsevier Ltd, 3(6), pp. 559–570. Available from: doi: 10.1016/j.jtte.2016.05.006. (Accessed: 13 May 2018).
26. Woolley, J. E., Dyson, C. B., Taylor, M., Zito, R. and Stazic, B. (2002) 'Impacts of Lower Speed Limits in South Australia', IATSS Research. International Association of Traffic and Safety Sciences, 26(2), pp. 6–17. Available from: doi: 10.1016/S0386-1112(14)60038-8. (Accessed: 26 July 2017).
27. Yingxue, Z. (2009) 'Analysis of the Relation between Highway Horizontal Curve and Traffic Safety', 2009 International Conference on Measuring Technology and Mechatronics Automation, ICMTMA 2009, 3, pp. 479–481. Available from: doi: 10.1109/ICMTMA.2009.511. (Accessed: 22 February 2017).

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