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A Simple Appraisal of Available Visibility Variation on Two-Lane Rural Roads

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Abstract: The continuing global mission for safer roads has led to many important ways for safety evaluation and improvement especially for two-lane rural roads. Available visibility is one element that has the combined function of speed, driver characteristics and the driving environment. Since, most fatal accidents occur at relatively high speeds, the driver's ability to accommodate and control successive variations of available visibility along the road is a very relevant safety component. This study is positioned to present the possibility of considering these variations directly, especially when the visibility values can easily be obtained. It is shown that road sections with high inconsistent visibility differentials have the highest possibility of crashes. The existing relationship between crashes and visibility along two-lane rural highways is upheld. Some technical recommendations and room for further research are proposed and advised.

Key words: Available visibility, sight distance, consistency, safety, two-lane rural roads, crash

INTRODUCTION

Road traffic crashes and collisions occur every day in different parts of the world claiming lives and causing millions of injuries out of which many victims are marred for life. According to the united nation decade of action on road safety 2011-2020, about 1.24 million people are killed on the world roads each year with more than 50 million injured (WHO., 2013). The recorded fatality and injury figures are reported to raise if no effort is made to counter the trend. It is estimated that nearly 60% of highway fatalities occur on two-lane rural roads outside cities or towns and about half of these fatalities occur on curved roadway segments. Accident research has consistently found that accident rates at horizontal curves are 3-5 times higher than the accidents rates on tangents sections of rural two-lane highways (Lamm *et al*., 2007).

This may indicate that by improving the accident-prone sections such as curves and obstructions along the roadway, a lot of lives could be saved. This improvement could be achieved by improving geometric design consistencies, thereby eliminating the possibility of sudden unexpected changes in driving conditions that often result in driver errors and consequently to accidents. The growing improvement in the design of automobiles in term of acceleration and speed has posed a huge challenge to transport engineers and planners towards finding optimal solutions that can safely accommodate those advances. Such demands for advances in the design of automobiles can be categorized under a consumer/product relationship. This rela-tionship is reported to also exist between the roads and road users (Matijoaitien and Stankevi, 2014). This, therefore, requires that roads should not only satisfy the requirements of aesthetics, economy and comfort but also, safety and efficiency. Safety and efficiency are often integrated into the design and operation of roads continually over their useful life.

A novel way to achieve safety on two-lane rural roads is by making the design consistent. Highway design consistency requires that the driver's expectations be in harmony with the successive changes of the alignment features, so that, no unexpected driving maneuver is required. Reseasch on design consistency and safety have been done in different part of the globe such as those by Fitzpatrick *et al*. (2000), Lamm and Choueiri (1988) and Lamm *et al*. (1995) each gave emphasis on two-lane rural roads and offering recommendations on how to evaluate design consistency for safer traffic operations. However, the available literature in the area of highway design consistency evaluation does not give a direct procedure of dealing with the variations in forward visibility. Therefore, this

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study is positioned to present the possibility of considering these variations directly, especially when the visibility values can easily be obtained. Available sight distance as an aspect of completed road alignment in term of geometry and traffic operation has been reported by Lamm *et al*. (1999) to be a very important component in road safety studies. Sight distance has been established as an important element in highway design by different design manuals including the Design Manual for Roads and Bridges (DMRB) of the United Kingdom, AASHTO Green Book of the United States of America. Each standard set out criteria to be fulfilled for minimum safe sight distances. However, the combined effect resulting from the interaction of available sight distances with alignment and traffic elements has remained a good area of interest to many research work such as those by Fambro *et al*. (2000), Fink and Krammes (1995) and Zirkel *et al*. (2012). This research investigates the effect of varying available visibility values on the possibility of traffic crashes on two-lane rural roads.

Background

Available visibility: Available Visibility (AV) is the length of the road visible to the driver from any given reference position along the road. AV is connected to the driver eyesight level, the height of object reference to the road surface, the speed of movement and the driver's conditions (Olson, 1984). AV can be influenced by nature of the terrain, road geometry, road furniture, traffic and abutting land use. While the values and nature of the influencing factors change along the road, values of AV in the form of distances, also changes giving a range of varying figures. When the available sight distance figures are higher the driver may likely develop some comfort leading to an increase in speed. The driver may as well be required to slow down when the values drop either abruptly or gradually.

Depending on the highway situations and driving circumstances, AV is expected to sufficiently support different forms of sight distances which include stopping Sight distance (dS), passing or overtaking sight distance (dP) and Meeting sight distance (dM) where applicable. There are several works on available sight distance on two-lane rural roads. Recently, Papadimitriou and Psarianos (2015) studied available sight distance and its connection with alignment geom-etry to address crashes involving wildlife in greece. An overview of the mathematical concept of sight distances is explained in Eq. 1-4.

The concept of highway design with regards to safe braking is based on the general assumption that braking occurs due to vehicle deceleration caused by frictional force from skidding tires regardless of the slope. Therefore, by considering basic kinetics of a vehicle moving at an inclined angle θ with forces of gravity and friction opposing each other, the braking distance can be given by:

$$d_B = \frac{V_1^2 - V_2^2}{2g\left(f\cos(\theta) - \sin(\theta)\right)} \tag{1}$$

where, V_1 and V_2 are initial and final velocities. Bearing in mind the smaller angular value of slopes for most highways, the cosine of small angles tends to approach unity. Based on the road slope geometry, sin θ equals tan θ which refers to the grade G. For a driver to safely bring the vehicle to a stop there has to be a combination of Reaction distance (dR) and Braking distance (dB). Therefore, the braking distance can be given by:

$$d_S = d_R + d_B = t_r V_1 + \frac{V_1^2}{2g(f \pm G)} \tag{2}$$

Three stages are involved for overtaking, namely, the distance S_1 traveled by the overtaking vehicle from the time the driver perceived and react to a slower vehicle in front. The distance traveled by the vehicle during overtaking on the opposing lane S_2 and the distance traveled by the oncoming vehicle during overtaking S_3. A passing maneuver may involve a driver to overtake more one vehicle and therefore, such cases should be considered when designing a highway (Llorca *et al*., 2015). The total passing distance can be written as shown in Eq. 3:

$$d_P = S_1 + S_2 + S_3 \tag{3}$$

Looking at the changes in velocity of the overtaking vehicle, the velocity of the slow moving vehicle (V_2), the distance maintained between the overtaking vehicle and the Slower vehicle (S_i), the velocity of the oncom-ing vehicle and the total time taken for the overtaking operation (T). Passing distance can be expressed as shown in Eq. 4:

$$d_P = V_1 + 2S_i + V_2\sqrt{\frac{4S_i}{g}} + V_2 T \tag{4}$$

Roads are constructed to satisfy some level of sight distance values but more often those values changes with a corresponding change in the alignment environment after the road has been constructed. Changes in the alignment environment could be due to land use and vegetation within the right-of-way. However, even if the specified requirements are satisfied there is the need for the available visibility values to be consistent along the road, especially on two-lane rural roads where overtaking and braking is crucial. Such inconsistencies are reported to generate significant influence between speed and sight distance (Altamira *et al*., 2010).

MATERIALS AND METHODS

Methods for statistical analysis: About 5 years road crash data was used in this research. A brief overview of the suitable method for statistical analysis is given together with the justification for its selection. Crash count data are non-negative integers and are considered inappropriate to be analyzed using methods that assume continuous dependent variables (Jovanis and Chang, 1986; Shankar *et al*., 1995). The use of Poisson regression has been 3 reported to be suitable for crash data analysis (Joshua and Garber, 1990; Miaou *et al*., 1992; Shankar *et al*., 1995; Tulu *et al*., 2015). Recently, poisson regression model was used in risk appraisal of passing zones involving passing sight distance on 19 passing zones in Uganda by Mwesige *et al*. (2015). Under Poisson Model the probability of having yi crashes over a certain period of time within a defined section of a road i is given by Eq. 5:

$$P(n_i) = \frac{EXP(-\lambda)\lambda^{ni}}{n_i!} \quad (5)$$

From Eq. 5, λ_i is a Poisson parameter for the road section i equivalent to the total annual crash count for that section. The Poisson parameter is commonly given as a function λ_i = EXP (βX_i) where X_i and β are v ector explanatory variable and estimable vector parameter, respectively. Although, Poisson regression models offer more depth compared to ordinary least square regression models, the problem of data over/under dispersion has been reported to undermine the efficacy of the model. This problem arises from the basic Poisson regression assumption that the mean of the data equals the variance ($E[n_i] = VAR[n_i]$). The assumption, however, cannot hold with crash count data, since, the chances of recording zero crashes within a road section i is highly likely. A modified form of poisson regression models such as those in the form of zero-inflated models has been reported to give good model estimations (Miaou, 1994). Detailed comparison on the choice of analysis methods for crash data was given by Lord and Mannering (2010) and Lord *et al*. (2005).

Some modification was made to the poisson regression model in the form of a Gamma function (Anastasopoulos and Mannering, 2009). Thus, the poisson parameter will be re-written as $\lambda_i = EXP(\beta X_i+\varepsilon_i)$ where EXP (ε_i) (having a mean equal 1 and variance α) is a corrective Gamma-distributed error term which will make the variance differ from the mean. Based on this improvement, the Probability Density Function (PDF) for negative binomial di stribution with Γ as gamma function can be written as:

$$P(n_i) = \left(\frac{1/\alpha}{1/\alpha+\lambda_i}\right)^{1/\alpha} \frac{\Gamma\left[(1/\alpha)+n_i\right]}{\Gamma(1/\alpha)n_i!}\left(\frac{\lambda_i}{(1/\alpha)+\lambda_i}\right)^{ni} \quad (6)$$

Likelihood functions are used to account for varying unobserved factors in the observations with random parameters. The estimable parameter β in the Poisson model can be re-written with a randomly distributed term φ_i in the form:

$$\beta_i = \beta+\varphi_i \quad (7)$$

Using Eq. 7, the Poisson parameter will become λ_i/φ_i = EX P(βX_i) and $\lambda_i/\varphi_i = EXP(\beta X_i+\varepsilon_i)$ for the poisson and negative binomial models, respectively. The term $P(n_i/\varphi_i)$ can be written in the PDFs of both models and according to Mannering, the Log-likelihood can be presented as:

$$LL = \sum_{\forall i} \ln\int_{\varphi i} g(\varphi_i)P(n_i/\varphi_i)d\varphi_i \quad (8)$$

where, g(.) is the PDF of the parameter φ_i.

The data and the study area: Three roads namely, B1280, B1283 and B6173 were selected from County Durham (North East England) as shown in Fig. 1 and 2. The roads satisfied the basic characteistics of a two-lane rural road. These roads comprise of various horizontal curves of different radii and vertical curves having a maximum slope of 8%. Accident record for the 5 years period shows that, these roads recorded over 70% of crashes compared to other road classes within the area. As shown in Fig. 2, B1280 is about 14 km starting from A182 moving through, the settlements of Haswell, Sotton and Wingate up to where it ends at A19. The road recorded an average of 3 crashes/km between 2010 and 2012.

Route B1283 begins from A1(M) motorway traversing through Sherburn village, Sherburn Hill and Haswell before closing on A182 over a total length of 16 km. The crash record for B1283 shows an average of 4 accidents/km for the same period with B1280. Route B6173 is 5 km long starting at a junction along route

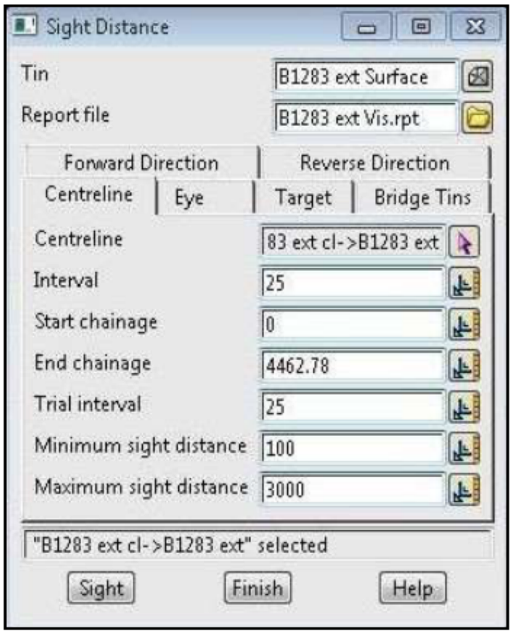

Fig. 1: Visibility measurement interface

A118 traversing through, Totonbie, Tanfield Lea and stanley before terminating on route A6076. The road recorded an average of 5 accidents/km between 2009 and 2011.

All the three roads had at some points passed through, built-up areas where in most cases the alignment requirement and traffic behavior changes. These changes come in the form of speed requirements and the junctions dynamics due to which, the driver may experience additional workload. The combination of several variables such as pedestrian movement and signage may cause temporary obstructions and may affect forward visibility. Due to the fact that drivers are required to stop at controlled junctions, such locations are not considered in this research.

The overall method involves the use of two basic type of data, road alignment and crash data in the STAT19 format (similar crash data can be obtained online from (CrashMap, 2017). AV values are estimated using a highway design software with a relevant extension similar to the function reported by Altamira *et al.* (2010) and Santos *et al.* (2008). In executing the visibility

Fig. 2: Map showing the study area (CrashMap, 2017)

measurement, the 12D highway design 4 software requires basic inputs that include the driver eyesight level, object height, vehicle trajectory string and the terrain surface for its inner working as shown in Fig. 1. The visibility values are calculated reference to the road surface at suitable horizontal distance interval. In this research, vehicle trajectory strings and Digital Elevation Model (DEM) were obtained and utilized to estimate AV values for a typical driver in both forward and reverse directions.

Alignment for each of the roads was carefully recreated from GIS data. This exercise was done using mapping tools and highway design software. A better alternative for alignment recreation is by scanning the whole road environment using a vehicle mounted radar or LIDAR, however, both are very expensive and relatively difficult to access in some countries.

A total of 31 sections of 2 km each for both direction of traffic were selected from all the 3 roads. Accident location coordinates were then imported into the road environment and matched with corresponding AV values. The resulting data is then studied and analyzed.

RESULTS AND DISCUSSION

Figure 3-5 show a typical plot of visibility difference (y-axis) against horizontal distance (x-axis) for all the roads. Crash locations are represented by the red vertical lines. It can be observed that, most crashes occurred at or near the locations of high values of AV difference. The high peaks in Fig. 3-5 indicate sections with relatively low AV.

For the purpose of this study, the number of accidents on the roads is categorized as occurring within the area of three value ranges of available visibility namely, 0-50 m (VR_1), 50-100 m (VR_2) and >100 m (VR_3). These values are proposed reference to sight distance thresholds in the (Design Manual for Roads and Bridges, United Kingdom) DMRB.

Figure 6 shows the percentages of accidents corresponding to each of the defined visibility values. Preliminary observation shows that more crashes occurred under VR3 despite having the highest visibility

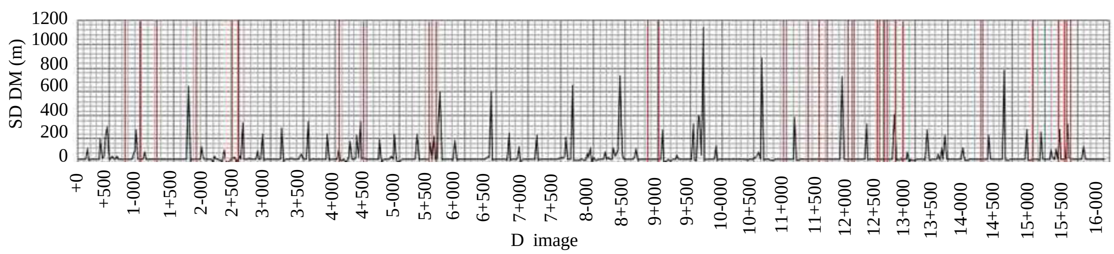

Fig. 3: Graphical representation of AV difference in the forward direction along B1280 (red vertical lines represent crash locations)

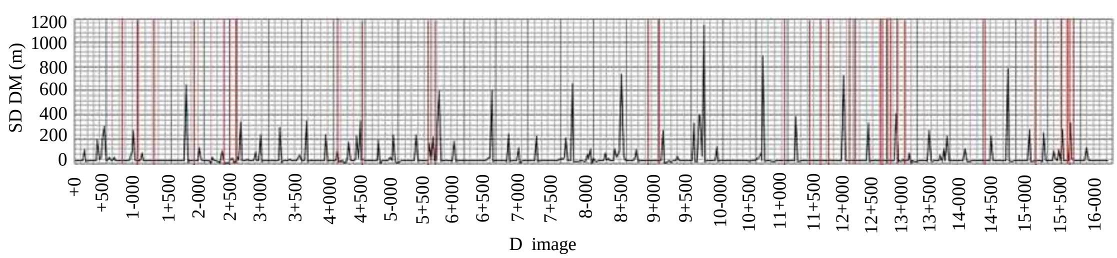

Fig. 4: Graphical representation of AV difference in the reverse direction along B1283 (red vertical lines represent crash locations)

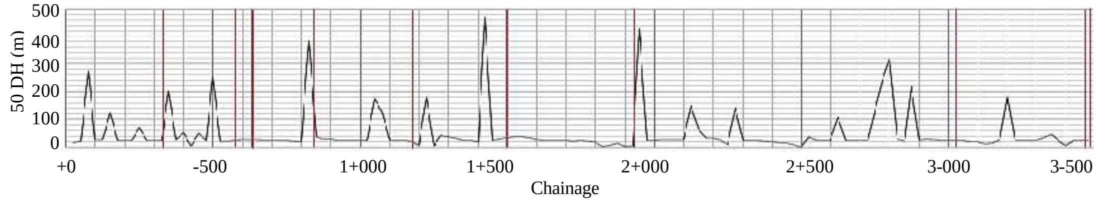

Fig. 5: Graphical representation of AV difference in the reverse direction along B6173 (red vertical lines represent crash locations)

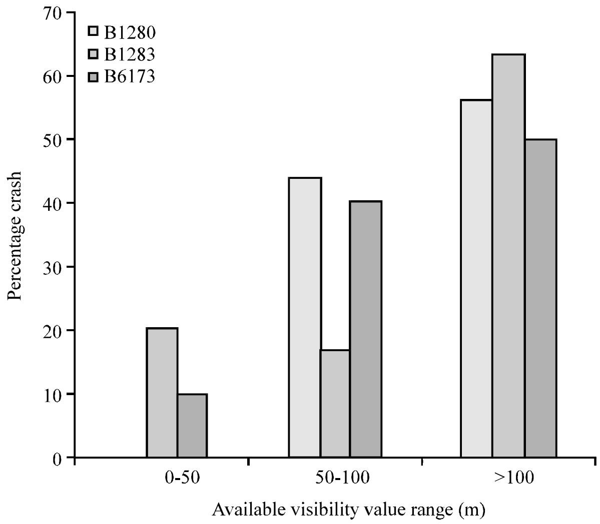

Fig. 6: Percentage crash by AV ranges

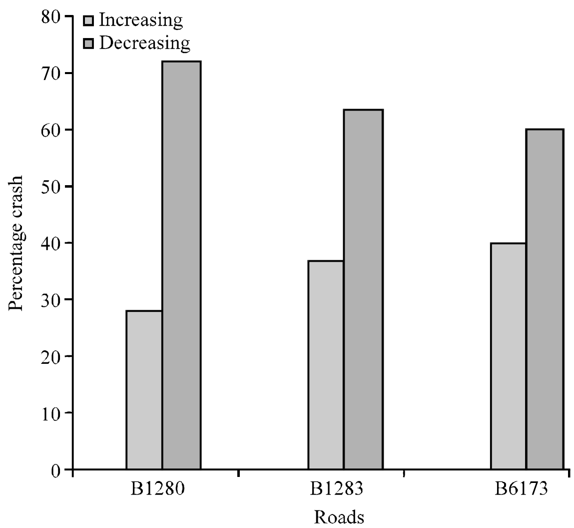

Fig. 7: Percentage accidents by increasing/decreasing AV transitions

values. Higher crash percentages for both VR_2 and VR_3 shows that drivers might have developed some speed before the unexpected changes in the AV values. Fewer crashes for VR_1 is shown also in Fig. 6. This may as well suggests that drivers are conscious of poor visibilityand therefore, became mindful by adopting lower speed. The data shown in Fig. 7 present percentage of the crash that occurred within sections where the AV values are either transitioning from lower to higher values (increasing) or from higher to lower values (decreasing). A Higher number of crashes is recorded at sections where AV changed from higher to lower values for all the roads. This could be an indication that sections where AV decreases

Table 1: Statistical summary

	Observations			
Variance	Min	Max	Mean	Variance
Dependent variable				
(5 years crash data within range)	1.00	9.00	4.226	7.047
VR_1 (0-50 m)	0.00	2.00	0.452	0.323
VR_2 (50-100 m)	0.00	8.00	1.484	3.591
VR_3 (>100 m)	0.00	7.00	2.290	3.942

Table 2: Relationship estimation results (p-values are shown in parenthesis)

	Relationship parameters	
Variables	Negative binomial	Poissonlog-linear
Constant	0.246 (0.585)	0.351 (0.099)
VR_1 (0-50 m)	0.234 (0.535)	0.190 (0.176)
VR_2 (50-100 m)	0.220 (0.042)	0.208 (0.001)
VR_3 (>100 m)	0.251 (0.019)	0.251 (0.001)

Observations (N), 31, 31; Log-Likelihood intercept (LL(β)), -79.086, -73.129; Log-Likelihood full model (LL(C)), -74.415, -49.804; Bayesian Information Criteria (BIC), 162.567, 113.345; ρc^2, 0.059, 0.319; $^*\rho c^2 = 1-(LL(\beta)/LL(C))$ (Hilbe, 2011; Lord *et al.*, 2005)

sharply are more likely to be prone to traffic crashes. These assertions are investigated using statistical techniques for count data.

Generalized linear model with poisson and negative Binomial distributions was used in the data analysis. These methods are suitable for count data as earlier discussed. The summary statistics shown in Table 1 revealed that a Generalized Linear Model will be appropriate for the data analysis. Two models were fitted and compared based on Pseudo R^2 values and Bayesian Information Criteria (BIC). Since, this resrarch is characterized by small sample size and few model variables BIC was considered to be more suitable for use in model comparison. Bayesian Information Criteria applies larger penalty term compared to other similar available tools (Neath and Cavanaugh, 2012).

Results of statistical analysis presented in Table 2 shows that VR_1 having visibility value range between 0 50 m has no significant possibility of crash at 95% confidence level. This result holds for both the negative Binomial and the Poisson models. The analysis also shows, for both VR_2 and VR_3 (having 51-100 and >100 m, respectively) there is a significance chance of traffic crash based on the defined data. Both models gave the same indication at 95% confidence level. The situation depicted in VR_3 sections can be an indication of driver's usual gain of speed within sections of high visibility. This driving behavior is also reported by Anarkooli and Hosseinlou (2015) who suggested that drivers tend to gain confidence in selecting higher speeds when the driving conditions are favorable with high visibility values. However, the driver's expectancy of the driving conditions will refute the actual situation when the available visibility begin to change sharply.

The statistical significance for VR_2 and VR_3 shown in Table 2 indicated that accidents are more likely to occur at sections where the visibility values suddenly transitioned from higher to lower values, more than the sections where the transition is from lower to higher values as shown by the graphical histogram in Fig. 3. This shows the resulting reaction of the driver from an increased workload due to accumulated uncertainties. Considering the results of the statistical analysis and the data from Fig. 3-5. It is clear that for all the roads, crashes occurred mostly within sections of varying visibility transitions and more importantly where the values of the variation are higher. Sections with a long inconsistent stretch of visibility values have fewer accidents compared to sections with huge variation in the visibility values over a short distance. For the former, the driver has already accustomed with the variations since they are consistent over a long section. While for the later, drivers may experience difficulty in adjusting to sudden huge changes in the visibility values. A similar trend was reported by Li *et al*. (2015) when the values of available visibility are drastically reduced by fog. This could, therefore, suggest that drivers develop some caution and understanding of the visibility situation. High values of decreasing visibility difference in the context of this study signifies low values of available visibility. Therefore, generally, the result indicates an inverse relationship between sight distance and accidents as highlighted by previous studies (Glennon *et al*., 1985; Lamm *et al*., 1999; Olson, 1984).

CONCLUSION

Based on the data presented, the statistical analysis and the discussions of the result it can be concluded that there is an inverse relationship between safety and the variation of available visibility on two-lane rural roads. This relationship can hold for roads with similar settings. From the analysis, it can be concluded that sections having visibility values of 51-100 and >100 m, respectively are more likely to record crashes. This is supported by both the negative Binomial model and the poisson log-linear model having the best fit (based on lower BIC and higherρc^2). There, for safe traffic operations the successive AV difference should be kept within 0-50 m for 2 km sections.

Generally, some level of safety could be achieved, if visibility differentials similar to those defined under range VR3 are minimized or avoided. For example, inconsistent horizontal curves that are in between consistent sections should be made to match AV properties of connecting tangents by improving their radii. Similarly, sections with high visibility values that are sandwiched between sections of low but consistent varying visibility values can have their high visibility matched by introducing roadside live screening in the form of vegetation, so that, the inconsistent effect is eliminated. Sections with low visibility values that are in between high but consistent varying visibility sections can be improved by either geometry upgrade, total realignment of the route, vegetation control or removal of any obstruction. This could be done provided that such remedial action is environmentally feasible and economically appraised and justified.

One of the major limitations of this study is the fact that both the vertical and horizontal alignments of the roads were recreated using secondary GIS data. The accuracy of the forward visibility values obtained defends on the accuracy of the recreated alignment. The most reliable means of obtaining more accurate visibility values is by using point clouds from road scan or by manual measurement. While the former is prohibitively expensive, the latter is time consuming and unsafe.

RECOMMENDATIONS

The research presented in this study is intended to position the argument about the influence of forward visibility variation on road safety. All the data used was obtained from online sources. Therefore, it is highly recommended to make use of primary on-site data and asbuild drawings when going forward on this attempt.

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