DOI: https://dx.doi.org/10.4314/gjpas.v27i2.13

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 27, 2021: 209-219
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ASSESSMENT OF ROAD SAFETY PARAMETERS IN THE CITY OF KIGALI, RWANDA

DAVID NKURUNZIZA, RAHMAN TAFAHOMI AND IRUMVA AUGUSTIN FARAJA

(Received 24 March 2021; Revision Accepted 30 April 2021)

ABSTRACT

Increase in vehicular population has led to increase in road crashes. This is particularly very evident in low- and middle-income countries. Rwanda is no exception to this problem. While various factors influence the occurrence of a crash, it is argued that road design can make roads either safe or unsafe to drive. This research examines geometric parameters of roads in the City of Kigali, with emphasis on checking their safety parameters in comparison with design standards of AASHTO 2011. The case study of this research was 'KN 123 St', a two-lane asphalt road located in the center of the City of Kigali. Road parameters like lane widths, curve radii, super-elevation, sight distances and slope grades were examined. The research found various areas of improvement, inconsistencies and non-conformities. The findings established a clear relationship between ignored safety parameters during design and construction, and road crashes that happened on specifically identified hazardous spots. For instance, there is an extreme abrupt change in lane widths over the whole length at a rate of 74%. Unsafe sharp curves make half of all evaluated horizontal curves. Curves with the smallest radii have already recorded many crashes. The study found that super-elevation values have been inadequately computed, designed, and constructed with an average variance of 5%. About 80% of assessed vertical curves had insufficient stopping sight distance and 90% of headlight sight distance likewise. Apart from geometric parameters, high operating speeds of car drivers and motorcyclists, lack of shoulders, lack of zebra crossings and left sidewalk were found as extra causes of traffic injuries. While widening of the road could potentially help meet most safety parameters, it is arguably expensive and unrealistic. Therefore, this study recommends speed governance, forgiving roadside features, traffic signalization, and road markings as tools to alert drivers where most crash-prone areas are.

KEYWORDS: Road safety, Geometric design, Safety assessment, Road Crashes, AASHTO 2011

1. INTRODUCTION

Road traffic injuries have been classified among top ten causes of human death worldwide (Pankaj 2016). It is argued that the number and severity of road crashes can be minimized after identifying root causes. There are three main players in a traffic crash scenario: road users, road conditions and vehicles. Traffic safety depends on good operation of the DVR-system 'Driver-Vehicle-Road-Environment' system. The road infrastructure plays a governing role in case of any road crash. This means that some road defects may trigger road crashes (Georgiev 2014). Therefore, a thorough assessment of road parameters must be conducted to convert the hazardous road stretches to safer ones by rectification of its parameters. Safety assessment is not a novel subject in road safety management. It is conducted worldwide and have proved to be an efficient and cost-effective tool for the improvement of road safety (Debald 2015). Safety assessment tries to identify road parameters that may present safety concerns and propose low-cost solutions or countermeasures to improve the road safety. A comprehensive checklist is based on different road parameters including operating speeds, roadside features, shoulders, drainage element, sight distances, roadway curvature, super elevation, gradient and so forth (Pankaj 2016).

According to Sarbaz (2009), basing on crash and road maintenance data from Western Sweden, he argued that there is a clear relationship between road design and road crashes. In his study, more than 3000 crashes, reported from 2000 to 2005 on median-separated roads, were collected and combined with road geometric and surface data. The statistical analysis showed variations

David Nkurunziza, University of Rwanda, College of Science and Technology
Rahman Tafahomi, University of Rwanda, College of Science and Technology
Irumva Augustin Faraja, University of Rwanda, College of Science and Technology

in crash rates when road elements changed confirming that road characteristics affect crash rates. Study results showed that large radii right-turn curves were more dangerous than left curves, particularly, during lane changing maneuvers. In addition to this, road surface results showed that both wheel rut depth and road roughness have negative impacts on traffic safety (Sarbaz, Robert and L. 2009).

In the USA, Fink (1995) showed that the level of curvature is a good predictor of crash rate on horizontal curves. Although the effects of approach tangent length and sight distance were not as vivid, the results suggested that the adverse safety effects of long approach tangent lengths and short approach sight distances became more pronounced on sharp curves (Fink KL 1995). In addition to this, there is another study which found that super-elevation, in combination with sharp curves, is the main factor of crashes on motorway access ramps (CETE 1995). However, Sakshaug (2000) disagreed and claimed the opposite, stating that there was a tendency towards higher crash risk for curves with high super-elevation than with low super elevation. Furthermore, Sakshaug found that crashes are related to the operating speed of the vehicle in the curves: high super-elevation – higher speed and higher risk; low super-elevation - lower speed and lower risk (Sakshaug 2000).

According to another Swedish study (Nilsson 2000) reviewing the influence of speed, there is an obvious improvement in traffic safety when speed limit is reduced. In another study in the northern part of Sweden, it was argued that reducing the speed limit from 110 to 90km/h resulted in a positive effect in terms of fatality rate, injury severity, and number of police reported crashes (Brüde 1998).

Following the Genocide against Tutsis in Rwanda in 1994, there has been dramatic socioeconomic development including a large influx of personal and commercial transport utilizing motorcycles (Rollason 2013). The number of licensed taxi companies and cooperatives in Rwanda has increased from just 13 in 2011 to 50 in 2014 and public transportation companies more than doubled from 25 to 57 during the same period (Patel, et al. 2016). Estimated road traffic deaths in Rwanda were some of the highest in the world in the 90's. While creation of Traffic Police in the year of 2000 helped reverting this situation, a 2015 national data survey suggests a rising trend in numbers of injured persons and deaths. In 2012, there were 4471 road traffic crashes throughout Rwanda with national statistics indicating 1451 injured persons and 220 deaths. This has increased up to 2508 injuries with 366 deaths in 2014 (N. I. NISR 2015).

Road crashes lead to huge social and economic losses. These crashes are often a result of unsafe road networks. Despite significant headway by the Government of Rwanda in road crashes prevention, including legislature of motorcycle helmet laws, limiting the number of passengers per vehicle or motorcycle and strict driving permits issuance among many others (RNP 2018); there continue to be high rates of road traffic injuries in Rwanda, specifically with young males and a vulnerable road user population, such as pedestrians and motorcycle users (Patel, et al. 2016). This study aims to find out if there were ignored parameters during road design and construction that may have consequently led to unfortunate road crashes.

2. METHODS

2.1 Safety Assessment Techniques

Safety assessments techniques vary from country to country. This study was conducted in a manner consistent with guidelines outlined by AASHTO (American Association of State Highway and Transportation Officials). AASHTO is a standard setting body based in the United States which distinguished itself in providing comprehensive guidelines to design and construction of roads. This study used the 2011 edition of AASHTO Green Book to establish a comparative base for assessment (AASHTO 2011).

Office and field work were employed to collect and analyze data. Office work involved the assessment of generally available data on the case study road. These details included road function, category, and traffic situation. The study inquired further road design data from the consultant who designed the road, CAVICON. The on-site field study involved the collection of road physical data using various tools:

Table 1: Equipment and tools used during the research

Tool	Use	Tool	Use
Safety vest	To enhance visibility during road inspection	Camera	To keep observation data
Tape measure	To measure longitudinal and sectional lengths	Speedometer	To record vehicle speeds
Dumpy level	To record road center-line elevations	GPS handle	To benchmark coordinates
Checklists	To guide the inspection process	Computer	To record & analyze data

2.2 Study Area

The city of Kigali is the capital of Rwanda and is home to just over 1 million people. It is made up of three districts namely, Gasabo, Kicukiro and Nyarugenge. It has a combined road density of 0.093km/km^2; paved roads and unpaved road density of 0.12 km/km^2 (Patel, et al. 2016). Kigali has experienced a tremendous increase in population which means crowded roads and the vehicle population also increased and is estimated at 200,000 including 80,000 motorcycles (RNP 2018).

The study area consists of a two-lane asphalt road that was already operational during this study. The road identification number is "KN 123 St". According to AASHTO, this road is categorized as an urban collector road[1], with a rolling terrain[2] and a minimum design speed of 50km/h[3]

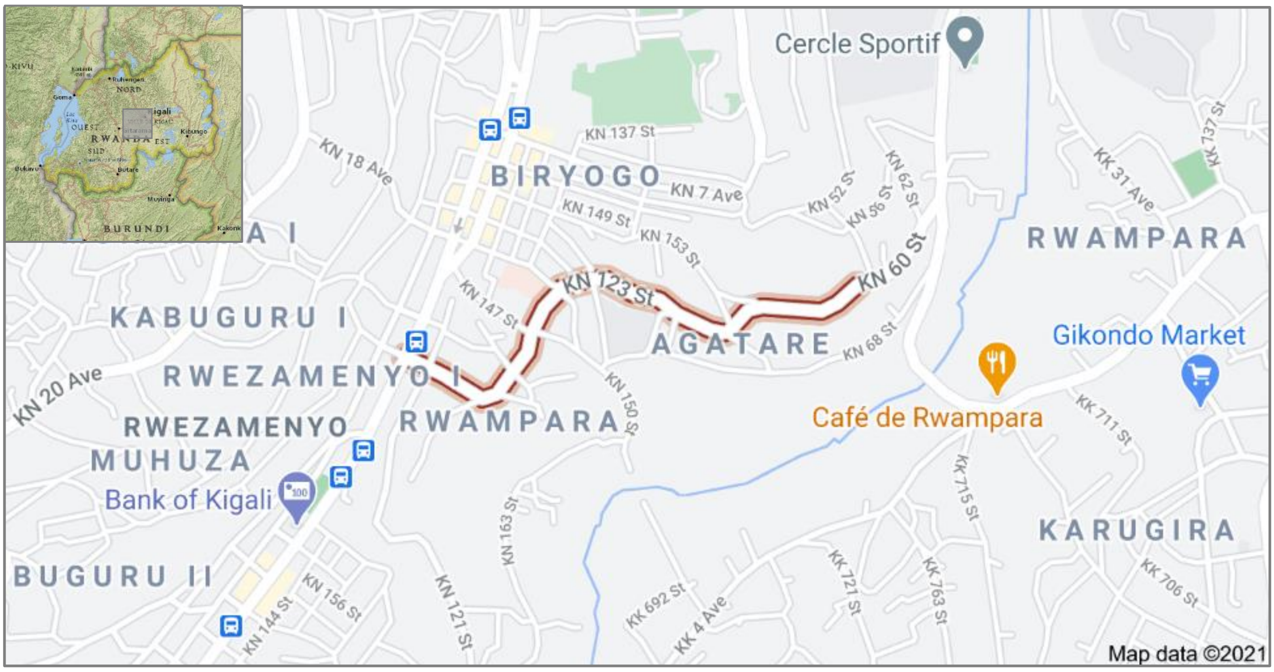


Figure 1: Street map of the case study in the City of Kigali (Source: Map data © Google Maps, 2021)

This road is geographically located in Nyarugenge district, at (3,346,016.5408m, -217,733.8145m, 1527.327m) approximate satellite location (Easting, Northing, Elevation), using UTM (Universal Transverse Mercator) coordinates for Rwanda, adapted for WGS1984 datum benchmarking.

According to Police data analyzed as at 2013, high density hotspots are mostly separated in the areas overlapping the downtown areas of Kigali, on the northern region of Nyarugenge, with the boundaries of Gasabo, and the southern part of Gasabo close to the boundaries to Kicukiro. These areas are the ones with larger concentration of grievous road traffic crashes (Patel, et al. 2016) as it can be seen on the figure above. As portrayed by Figure 2; clearly, Nyarugenge district has the higher rate of crashes than the other two districts of the City of Kigali. This gave significance to the case study selection, there was no better site to conduct a road safety assessment of than in Nyarugenge

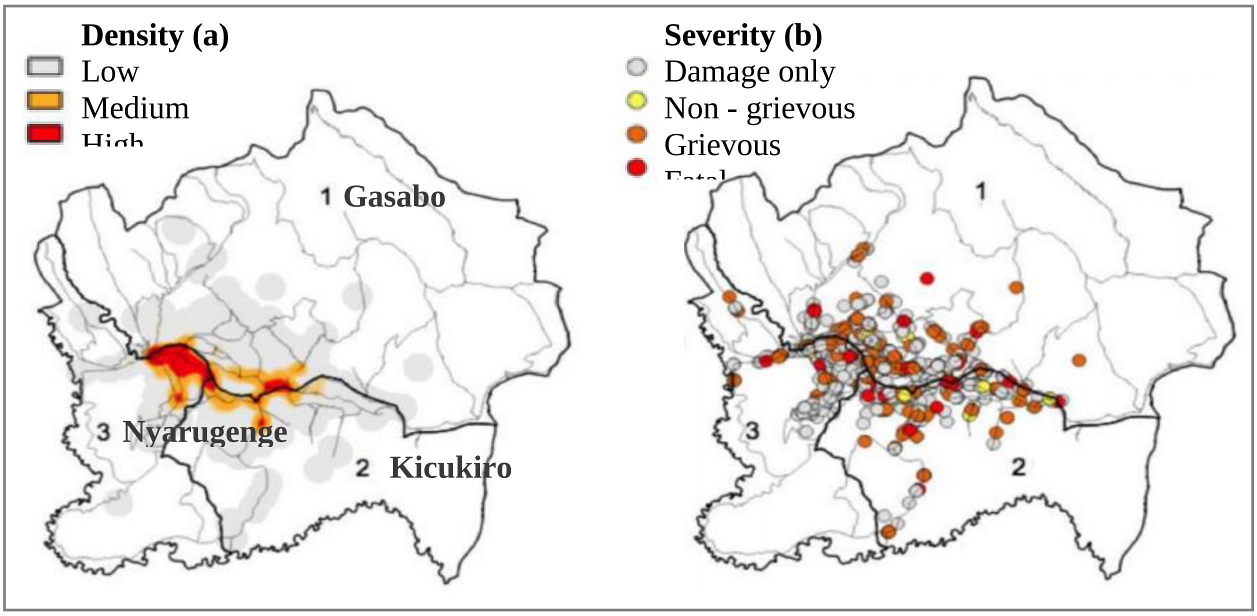


Figure 2: a) Police data crashes kernel density analysis of high, medium, and low-density areas of all types of road traffic crashes. b) Road traffic crash locations by severity of crash in Kigali districts. c Road traffic crash locations on a Kigali road map with highlighted areas of high-density crashes (Source: *(Patel, et al. 2016)*).

2.3 ASSESSED PARAMETERS

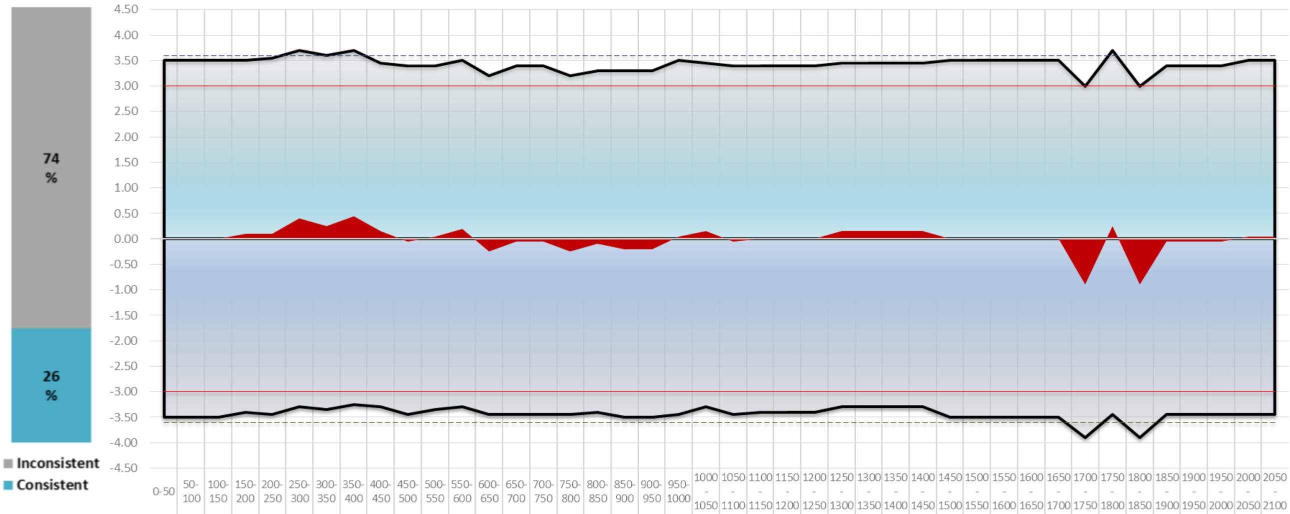
Road design and construction involves a combination of various complex parameters. While geometric aspects of a road may influence its safety at a larger extent, other parameters like access control, pedestrian sidewalks, shoulder provision, traffic volume control, forgiving roadside features, road markings and many other parameters, will continue to play an important role in road safety. For the sake of brevity, this paper assesses five geometric parameters of the case study road.

Table 2: Parameter definition and safety design criteria

Parameter Definition	**Safety Design Criteria (AASHTO 2011)**
Road characteristics: **(1)** Urban collector road **(2)** Rolling terrain **(3)** 50km/h design speed	
1. Lane Width	
Road width affects the capability of driver to perform evasive maneuvers and determine the lateral clearances both between vehicles and between vehicles and other road users.	An optimum lane width value ranging from **3m to 3.6m**[4] is adopted for safe and comfortable riding.
2. Curve Radius	
Road geometric design involves horizontal and vertical curves. It is arguably one of the parameters that engineers closely watch over to make right and left turns safer. When the radius is smaller, the crash rate is higher.	Derived from the design speed (V= 50km/h), the minimum radius is **79m**[5] and is determined from the rate of super elevation (e_{max}= 6%) and side friction factor (f_{max}= 0.19) selected for design. $$R_{\min} = \frac{V^2}{127(0.01e_{\max} + f_{\max})}$$
3. Sight Distance	
The ability to see ahead is necessary for safe operation of a vehicle. Two main sight distances have been assessed: **SSD:** Stopping Sight Distance: A near worst-case distance a driver needs to be able to stop. **PSD:** Passing Sight Distance: Minimum desired sight distance required to safely overtake a front vehicle.	SSD depends on both reaction time (t=2.5s) traveled distance and deceleration braking distance (a=3.4 m/s^2). PSD is derived from SSD. $$SSD = 0.278Vt + 0.039\frac{V^2}{a}$$ SSD_{min} = **74m** and PSD_{min} = **160m**[6].
4. Super-elevation	
A transverse slope that results from raising pavement outer edge with respect to the inner edge is necessary to counter-act the effect of centrifugal force and reduce the tendency of vehicle to overturn and skid laterally outwards while moving along a curve. Improper super-elevation value or no super-elevation at all may cause an crash.	Super-elevation '**e**' is a complex parameter that largely depends on highway side friction '**f**' which in return affect the radius **R** for a curve. Other factors include running speed, environment, traffic volume, surface drainage, etc. The relational equation is: $$\frac{0.01e+f}{1-0.01ef} = \frac{v^2}{gR} = \frac{0.0079V^2}{R} = \frac{V^2}{127R}$$ For 'KN 123 St' $\mathbf{e_{max}}$ should **6%**[7] or lower.
5. Grades	
A longitudinal slope measured as vertical rise or fall per 100 meters, is an important safety parameter for vertical alignment. Steeper gradients are generally associated with higher crash rates.	The maximum grade for safety reasons for an urban collector road at a design speed of 50km/h with a rolling terrain is **11%**[8].

3. RESULTS

3.1 Lane Widths



	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	600-650	650-700	700-750	750-800	800-850	850-900	900-950	950-1000
Lane width right	3.5	3.5	3.5	3.5	3.55	3.7	3.6	3.7	3.45	3.4	3.4	3.5	3.2	3.4	3.4	3.2	3.3	3.3	3.3	3.5
Lane width left	-3.5	-3.5	-3.5	-3.4	-3.5	-3.3	-3.4	-3.3	-3.3	-3.5	-3.4	-3.3	-3.5	-3.5	-3.5	-3.5	-3.4	-3.5	-3.5	-3.5
Inconsistencies	0	0	0	0.1	0.1	0.4	0.25	0.45	0.15	-0.1	0.05	0.2	-0.3	-0.1	-0.1	-0.3	-0.1	-0.2	-0.2	0.05
AASHTO Max Right	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
AASHTO Min Right	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
AASHTO Min Left	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
AASHTO Max Left	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6

	1000-1050	1050-1100	1100-1150	1150-1200	1200-1250	1250-1300	1300-1350	1350-1400	1400-1450	1450-1500	1500-1550	1550-1600	1600-1650	1650-1700	1700-1750	1750-1800	1800-1850	1850-1900	1900-1950	1950-2000	2000-2050	2050-2100
Lane width right	3.45	3.4	3.4	3.4	3.4	3.45	3.45	3.45	3.45	3.5	3.5	3.5	3.5	3.5	3	3.7	3	3.4	3.4	3.4	3.5	3.5
Lane width left	-3.3	-3.5	-3.4	-3.4	-3.4	-3.3	-3.3	-3.3	-3.3	-3.5	-3.5	-3.5	-3.5	-3.5	-3.9	-3.5	-3.9	-3.5	-3.5	-3.5	-3.5	-3.5
Inconsistencies	0.15	-0.1	0	0	0	0.15	0.15	0.15	0.15	0	0	0	0	0	-0.9	0.25	-0.9	-0.1	-0.1	-0.1	0.05	0.05
AASHTO Max Right	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
AASHTO Min Right	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
AASHTO Min Left	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
AASHTO Max Left	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6

Figure 3: Variability of lane width on KN 123 Street

As measured on site, it was observed that lane widths fall in the specified range but are inconsistent and vary for different chainages. It was also found out that there was an incorrect lane division whereby lane widths on the left and right sides were not equal. It was evident that 74% of evaluated chainages had inconsistent lane widths. Both PK 1+700 and PK 1+800 stations proved critical due to an abrupt change of about 1m from the left lane to the right lane. This is a recipe of road traffic crashes and therefore quite unsafe.

3.2 Road Curves

Road geometry is composed by both linear paths and circular or parabolic paths called curves. The researchers managed to gather physical data on the existing road geometry. Using GIS technology, also managed to reference the existing road centerline to the real coordinates. World Geodetic System as of 1984 has been used as the datum and Autodesk Civil3D Software has been used to solve complex calculations, such as for super elevation, bearing in mind AASHTO 2011 design standards.

Table 3: Horizontal alignment curves

No.	Start Station	End Station	Length [m]	Radius [m]	Delta Angle [d]	Start Direction	Calculated Super-Elevation [%]	Measured Super-Elevation [%]
1	0+159.37m	0+204.24m	44.865	135.144	19.021	S67° 15' 51"E	0.2%	5.4%
2	0+209.34m	0+234.31m	24.970	16.572	86.327	S48° 14' 36"E	3.8%	6.0%
3	0+251.36m	0+269.69m	18.335	200.000	5.253	N45° 25' 48"E	0.5%	4.6%
4	0+310.41m	0+329.00m	18.591	200.000	5.326	N40° 10' 38"E	0.7%	4.6%
5	0+348.73m	0+377.82m	29.095	171.151	9.740	N34° 51' 05"E	0.1%	5.0%
6	0+380.96m	0+393.61m	12.650	47.617	15.221	N25° 06' 41"E	0.1%	6.0%
7	0+417.62m	0+424.75m	7.131	75.682	5.399	N9° 53' 25"E	0.1%	6.0%
8	0+430.30m	0+463.15m	32.850	81.354	23.135	N15° 17' 21"E	0.1%	6.0%
9	0+472.85m	0+484.45m	11.601	55.029	12.079	N38° 25' 28"E	1.9%	6.0%
10	0+498.50m	0+562.70m	64.199	101.069	36.394	N24° 23' 13"E	0.3%	6.0%
11	0+563.50m	0+577.41m	13.909	73.811	10.797	N60° 46' 52"E	0.1%	6.0%
12	0+618.18m	0+671.26m	53.079	71.182	42.724	N72° 44' 30"E	0.6%	6.0%
13	0+700.07m	0+715.07m	15.003	126.835	6.777	S61° 03' 52"E	0.8%	5.6%
14	0+725.05m	0+736.13m	11.079	130.672	4.858	S67° 50' 30"E	0.8%	5.4%
15	0+756.52m	0+775.72m	19.203	335.918	3.275	S72° 41' 58"E	0.8%	3.6%
16	0+794.03m	0+821.51m	27.481	63.962	24.617	S75° 58' 29"E	0.8%	6.0%
17	0+846.80m	0+874.62m	27.821	105.044	15.175	S52° 56' 17"E	0.0%	5.8%
18	0+893.02m	0+906.41m	13.390	50.000	15.344	S68° 06' 47"E	0.0%	6.0%
19	0+912.75m	0+921.47m	8.721	60.622	8.243	S52° 46' 08"E	0.0%	6.0%
20	0+933.10m	0+941.62m	8.520	59.764	8.168	S61° 00' 42"E	0.0%	6.0%
21	0+962.36m	1+012.25m	49.898	40.717	70.216	S69° 10' 47"E	0.0%	6.0%
22	1+022.36m	1+022.57m	0.209	50.000	0.240	N40° 36' 17"E	0.0%	6.0%
23	1+048.64m	1+086.81m	38.165	50.000	43.734	N40° 50' 40"E	0.0%	6.0%
24	1+102.92m	1+129.04m	26.123	134.399	11.136	N86° 26' 23"E	0.0%	5.4%
25	1+225.35m	1+264.87m	39.525	60.101	37.680	S82° 12' 42"E	0.1%	6.0%
26	1+293.41m	1+316.18m	22.773	91.835	14.208	N57° 57' 27"E	0.1%	6.0%
27	1+340.42m	1+369.07m	28.645	51.593	31.811	N42° 49' 47"E	1.0%	6.0%
28	1+391.15m	1+414.20m	23.044	158.095	8.352	N77° 53' 59"E	1.0%	5.0%
29	1+414.21m	1+462.17m	47.962	117.286	23.430	N69° 32' 54"E	0.5%	5.6%
30	1+483.30m	1+489.16m	5.864	61.783	5.438	N44° 57' 52"E	0.5%	6.0%
31	1+505.68m	1+548.04m	42.364	117.697	20.623	N39° 31' 35"E	1.0%	5.6%
32	1+581.27m	1+584.68m	3.411	55.043	3.551	N18° 54' 11"E	0.5%	6.0%
33	1+585.32m	1+617.28m	31.956	60.748	30.140	N15° 21' 09"E	0.4%	6.0%
34	1+636.09m	1+639.92m	3.837	24.987	8.798	N45° 29' 32"E	0.2%	6.0%
35	1+640.43m	1+696.87m	56.439	83.041	38.941	N36° 41' 41"E	0.7%	6.0%
36	1+739.17m	1+794.46m	55.298	398.276	7.955	N5° 50' 34"W	3.6%	3.4%
37	1+948.91m	2+012.17m	63.256	445.327	8.139	N0° 13' 32"E	1.5%	3.0%
38	2+022.38m	2+080.87m	58.487	556.844	6.018	N8° 21' 50"E	1.4%	2.6%

Figure 4: Road alignment plan vie
w and station visualization. Chainage length is from 0 to 2.18Km.

Table 4: Vertical Alignment Curves

No.	Station	Elevation [m]	Grade In	Grade Out	A (Change)	Curve Length [m]	K Value	Curve Type
1	0+000.00m	1527.327		-5.41%				
2	0+091.06m	1522.401	-5.41%	-21.65%	16.24%	147.475	9.082	Crest
3	0+224.74m	1493.463	-21.65%	-1.46%	20.19%	23.793	1.178	Sag
4	0+295.19m	1492.436	-1.46%	-10.21%	8.76%	18.387	2.100	Crest
5	0+389.68m	1482.785	-10.21%	8.00%	18.21%	53.92	2.961	Sag
6	0+449.23m	1487.548	8.00%	-0.49%	8.49%	38.902	4.582	Crest
7	0+476.81m	1487.413	-0.49%	4.99%	5.48%	13.353	2.435	Sag
8	0+547.17m	1490.925	4.99%	-10.09%	15.08%	71.611	4.749	Crest
9	0+613.39m	1484.244	-10.09%	4.12%	14.21%	20.005	1.408	Sag
10	0+648.75m	1485.701	4.12%	-9.30%	13.42%	39.139	2.917	Crest
11	0+713.86m	1479.647	-9.30%	-3.89%	5.40%	36.983	6.844	Sag
12	0+797.99m	1476.372	-3.89%	-6.88%	2.99%	25.026	8.382	Crest
13	0+857.24m	1472.296	-6.88%	-1.58%	5.30%	28.391	5.362	Sag
14	0+903.75m	1471.559	-1.58%	-10.33%	8.74%	43.642	4.992	Crest
15	0+984.24m	1463.248	-10.33%	8.39%	18.71%	65.59	3.505	Sag
16	1+078.81m	1471.178	8.39%	-11.19%	19.58%	85.789	4.383	Crest
17	1+267.82m	1450.029	-11.19%	-3.21%	7.98%	36.083	4.521	Sag
18	1+304.01m	1448.868	-3.21%	1.25%	4.45%	19.491	4.376	Sag
19	1+356.99m	1450.401	3.87%	-8.55%	12.43%	31.803	2.559	Crest
20	1+406.87m	1446.135	-8.55%	-5.01%	3.54%	8.241	2.329	Sag
21	1+529.25m	1439.367	-6.32%	0.51%	6.83%	47.641	6.974	Sag
22	1+595.14m	1439.705	0.51%	-15.37%	15.88%	38.41	2.418	Crest
23	1+663.75m	1429.159	-15.37%	-0.12%	15.25%	47.734	3.129	Sag
24	1+766.61m	1429.039	-0.12%	-2.95%	2.83%	63.181	22.332	Crest
25	1+882.98m	1425.612	-2.95%	-0.67%	2.27%	96.064	42.279	Sag
26	1+980.30m	1424.956	-0.67%	-7.35%	6.68%	78.387	11.742	Crest
27	2+180.00m	1410.000	-7.35%					

3.3 ROAD GEOMETRY ANALYSIS

Using advanced data visualization techniques, it was possible to be able to spot key safety issues along road length geometry. It is assumed that the more design standards are violated, hazardous the riskier it becomes to ride a particular section of the road. The following chart shows curve radii distribution along road stations.

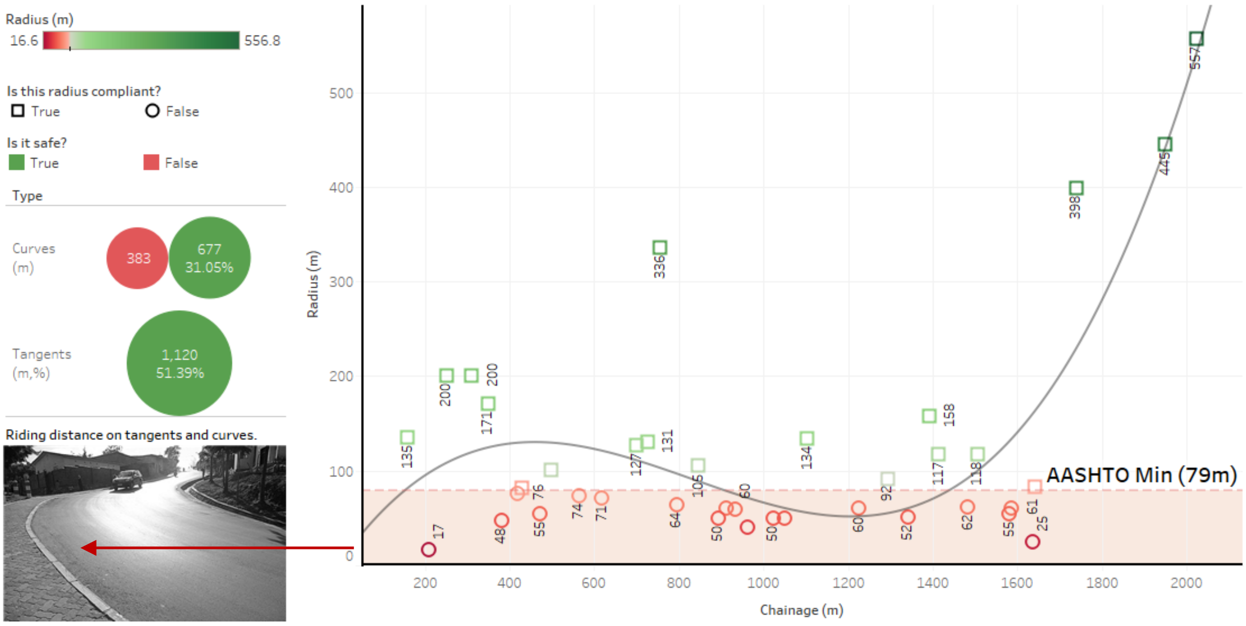


Figure 5: Checking for curve radii

As cited earlier, suitable super-elevation values for urban collector roads in rolling terrain will not exceeding 6%.[9] It is a general establishment that smaller radii require stepper super-elevation to reduce overturning risk of running cars. The researchers both calculated suitable **e** values for assessed curves and compared them to actual **e** values on the road. The contrast is vivid. This poses a safety risk.

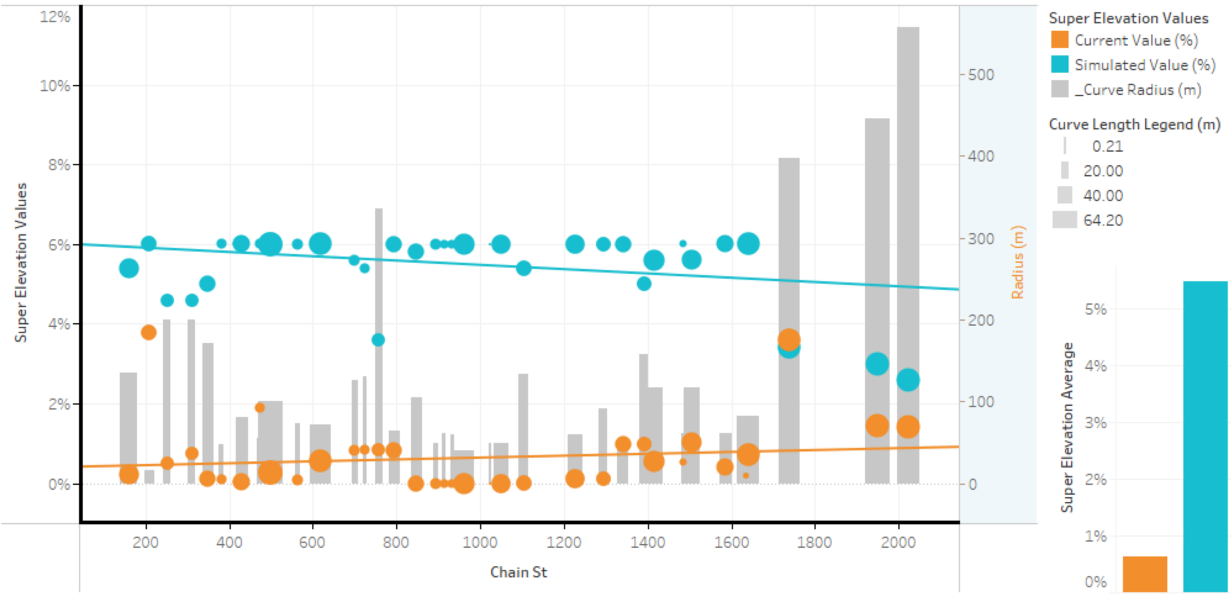


Figure 6: Checking for curve super-elevations

The last graph showcases safety concerns on road grades vertical curves as early defined. The road is composed by 25 vertical curves. AASHTO 2011 refence values have been benchmarked on the graph to provide a clear contrast.

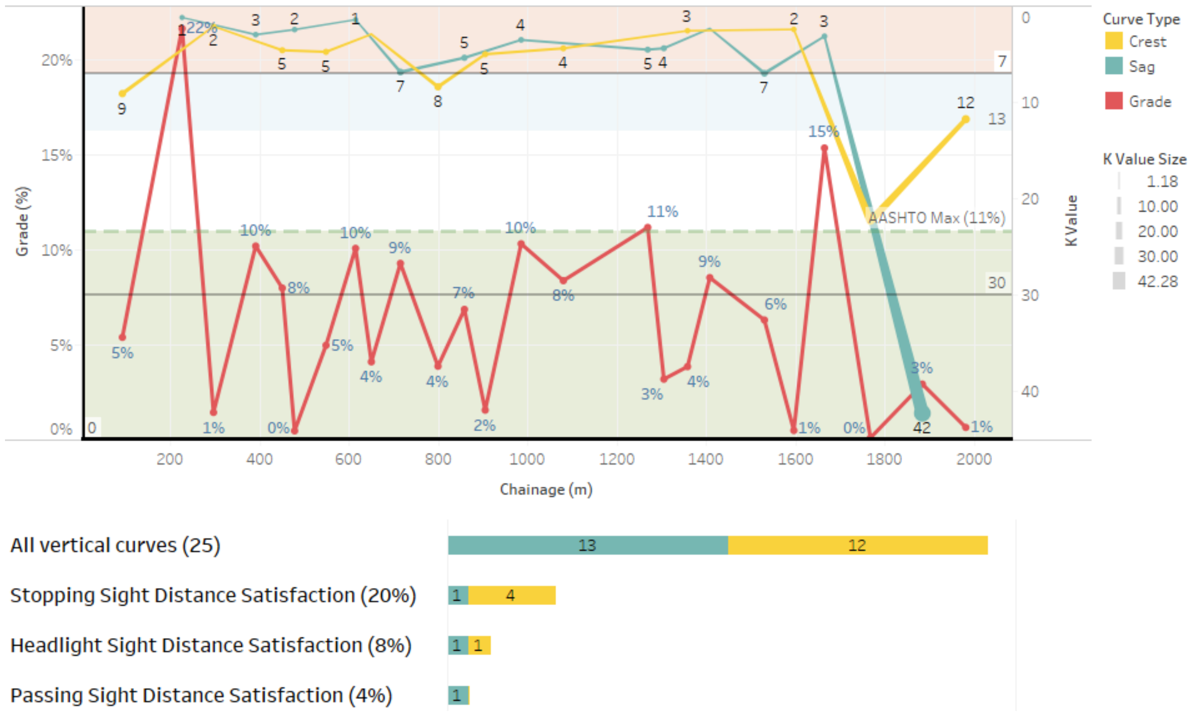


Figure 7: Checking for vertical curves, grades, and sight distances

DISCUSSIONS

4.1 GEOMETRIC PARAMETERS

The findings showed that the horizontal alignment of the road was made by an almost equal share of straight tangents and curves. About 383m of the road that compose about a fifth of the total road length tend to be unsafe for right and left turns. An extended computational analysis of radius data along road chainage, using a polynomial regression line of third degree, showed that the road tend to have smaller and unsafe radii in the beginning and ends in more straight tangents. Radii around station PK 0+0200 and PK 0+1600 as showed on the picture, pose a hazardous riding risk to drivers. This is according to AASHTO 2011 table on computed safe minimum radius for a 50km/h design speed.

Next, There was a visible deflection between simulated super elevation values, with an average of about 5.5%, and actual measured values on site. The actual average value of countering centrifugal forces is about 0.6%. This is quite inadequate, toping the fact that a half of all curves are below a safe radius. On the flipside, a maximum super elevation of 6% is proposed as calculated. Visibly, the road section that seems safer with small e values is the one from station 1800, and for this at last, there is a close correleration between site and theory values.

The analysis of vertical curves showed that the design adhered to maximum grades of 11%, as outlined by AASHTO, with the exception of three occasions that presents about 10% of all vertical curves and tangents. This being however, there is a serious safety risk around station 200 and 1700, raised by a 22% and 15% slope respectively. When car brakes are not adequate enough, there is a high risk of collision. Also, note that these same spots, refering to the horizontal plan view of the road alignment, have sharp curves ahead and therefore a high hazard roadside traffic crash.

Figure 8: Road photographs on Station PK 0+050, PK 0+100 and PK 0+200, respectively

The vertical alignment analysis went further to assess sight distances of profile curves. According to elevation and contour, the road is located I on a area. This could have presumably forced designers to adopt unforgiving K-values in the design process. In literal terms, it is a drive on your own risk, to ride on road where only a fifth of all curve tend to provide an adequate stoping sight distance, with minimal night vision clearance of about 8% and almost restricted overtaking. K-values are used to simply curve design process, when the grade abolute difference and curve length are known. As the road gets flatter, only then sag curves with a 42 K value, it becomes relatively safer than previous sections. A sag curve with K=42 satisfies three sight distance (greater than 30 for PSD, >13 for HSD and 7 for SSD),

Coupling these safety concerns with those discussed earlier on lane widths and horizontal curves, KN123St has proved unsafe and its users should be alerted by all means to avoid any unfortunate crash happening.

4.2 NON-GEOMETRIC PARAMETERS

As specified by the speed limit sign on station PK0+050, vehicles using the road KN 123 St should adhere to a maximum 40km/h speed limit. During the site visit the speedometer records showed that 85^{th} percentile operating speeds on this road exceed the established speed limit. Many drivers' speeds range from 60-80 km/h especially during hours of low traffic between 09:00 a.m. and 12:00 a.m. in the morning; from 3:00 p.m. to 5:00 p.m. in the afternoon and during the night. During this period, drivers expect less traffic and tend to run at higher speeds. Elevated operating speeds increase the grievous collision probability.

Next, roadside features have been qualitatively assessed and issues noted. As shows the photograph, during the site visit, it has been noticed that for the road lacks shoulders. Shoulders are special lanes for accommodation of stopped vehicles and for emergency use in case a vehicle is disabled while moving along the road. Lack of adequate clear area and refuge for disabled vehicles increases the risk for a roadside collision (Harkey D. L. 2008). Likewise, roadside barriers prevent vehicles from running off the road on tight curves and steep slopes (Sawalha Z. 2001). They are generally established to avoid single vehicle run-off road crash (Zegeer, et al. 1988). The road lacks competent barriers to do this job as shows the capture on chain 200. In addition to this, there is only one sidewalk on the left side of the road. Biryogo is a high-density residential area. This sidewalk is arguably smaller and causes what researchers called "pedestrian traffic jams". It is therefore of utmost importance to realize the safety hazard hedged towards non-motorized users of KN123St.

4.3 LIMITATIONS

The study was conducted with the assumption that roads that comply with AASHTO 2011 are safe. The researchers assumed safety hazard weight on various road spots, by varying violation degree of suitable design values against actual measured values. According to Hauer (2000), a standards skeptic, he argued that while many people believe that roads designed to standards are safe; they are really neither safe nor unsafe. He claims that their safety is largely unpremeditated. After relating relate three historical anecdotes on three prominent geometric standards: vertical crest curves, lane width and horizontal curves, he came to a skeptical conclusion that design standards were written and repeatedly rewritten without factual knowledge of their repercussions on crash frequency and severity (Hauer 2000).

Additionally, AASHTO claims that its design parameters are not universal and may not be suitable in special various situations. The case study road is in Rwanda while historic simulations and that produced standard tables were all done in the United States, a country with a distinct topography and terrain. Therefore, considering the complexity of Rwanda's topography, researchers admit that all unsafety claims made in this paper, may be overstated, only because the reference used is or could be limited under some circumstances. It is also admitted that data used in the research paper rely on the accuracy of used GIS mapping techniques, updated by both Google and Microsoft, to access UTM coordinates for Rwanda, via satellites, adapted for WGS1984 datum benchmarking.

4.4 RECOMMENDATIONS

Safe riding is the goal engineers design roads. Adherence to design standards is therefore paramount to ensuring road safety. Collected data on KN 123 St exposed various safety concerns, that should alert both road users and road contruction authorities in the country of Rwanda. According to Patel et al. (2016), Rwanda has made vast improvements to its infrastructure. This gave way to more road users and hence more grivious and fatality potentials. Though road design alone could not solve all road safety issues, engineers have to play their utmost role in minimizing predictible risks.

The improvement in road parameters themselves would involve high costs. From both economic and engineering point of view, solutions must be sustainable and cost effective. Expropriation and reconstruction must be avoided at all costs. To tackle poor visibility problems on sharp curves, it is recommended that unnecessary building extensions, structures, mounds, trees, or wire poles must be removed at sight triangles of intersections or at the inner sides of horizontal curves in some circumstances. This can increase the visibility of convex mirrors, warning signs, and pavement markings and reduce crash risks.

It has also been noted during the assessment, that operating speeds exceed the signalized speed limit, and this is a hot recipe of crashes. Speed regulation enforcement could be the remedy. This suggestion would implement various means to reinforce the posted speed limit. That might involve increased police presence, setting up speed display devices, and increasing speed limit enforcement (writing more tickets for those who exceed the speed limit). This would require the installation of police pull-off locations for safer enforcement operations.

In a nutshell, as redesign and reconstruction already proved expensive, it is recommended to put enough traffic signs and road markings to increase awareness of unusual road geometric parameters susceptible to trigger crashes such as sharp curves, locations of a high sequence of curves, high grades, and abrupt change of lane widths. Availing adequate zebra crossings to allow convenient crossing of pedestrians, and humps at critical sections of the road could also help reduce the problem of uncontrollable over speeding.

5. CONCLUSION

This study was conducted to assess safety parameters of roads in the City of Kigali. At a larger extent, evaluated parameters proved unsafe for riding. Lane widths were inconsistent at a rate of 74%. Unsafe sharp curves make half of all evaluated horizontal curves. Curves with the smallest radii have already recorded many crashes. About 80% of assessed curves had insufficient stopping sight distance and 96% of passing sight distance likewise. A huge 5% super-elevation average variance has been noted between actual and simulated values. Only 10% of evaluated

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