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Identifying infrastructure risk factors in Africa

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Abstract

The paper aims to provide a critical overview of the infrastructure risk factors in African countries performed within the research project "SaferAfrica - Innovating dialogue and problems appraisal for a safer Africa". The project is funded by the European Commission's Horizon2020 research and innovation programme. Both macroscopic (generic level) and microscopic (infrastructure element level) potential risk factors were examined and discussed. The macroscopic infrastructure risk factor analysis was based on WHO mortality data and revealed a weak but existent relationship between an extensive road network and fatality rates in African countries. On the other hand, the microscopic infrastructure risk factors analysis, based on technical reports and scientific papers, showed various potential factors, such as low road width, curve radius, low median width, absence of street light etc. Although some research has been carried out in the field of infrastructure risk factors and road safety, the major identified drawback is the lack of available data. Therefore, it is strongly suggested to validate the empirical findings with real-African data. Such an analysis accompanied with reliable and accurate data consists the basis for identifying priority areas for road safety actions and interventions.

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Keywords: road safety; macroscopic risk factors; microscopic risk factors; reliable data

1. Introduction

In the European Union (EU), during the past two decades, a substantial progress has been achieved in improving road safety and reducing traffic fatalities. For instance, in the decade up to 2010, the fatality figures and the total

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number of injured were reduced by 45% and 30% respectively (EuroStat, 2012). However, this is not the case for Africa.

Africa is the worst performing continent in road safety. As shown in Figure 1, the mortality rate in Africa (26.6 fatalities/10^5 population) is almost three times that of Europe's, where the number of road fatalities represents 31% of the relevant global figure. However, the most disturbing concern is the fact that the disparity in road safety results seems to be increasing. Specifically, according to the World Health Organisation (WHO, 2015), in Europe, fatality rates improved from 10.3 per 100,000 population in 2010 to 9.3 per 100,000 population in 2013. Over the same period, road fatality rates in Africa, increased from 24.1 per 100,000 population to 26.6 per 100,000 population. As far as Africa is concerned, road trauma is expected to worsen further, with fatalities per capita projected to double from 2015 to 2030 (WHO, 2015).

Europe could definitely play an important role in supporting African countries to improve their road safety and traffic management performance. Such considerations are addressed through the SaferAfrica project (http://www.saferafrica.eu/), an Horizon2020 Coordination and Concerted Action. The project is a joint effort of 17 partners from both continents, aiming to create favorable conditions and opportunities for the effective implementation of road safety and traffic management actions in the African countries by setting up a Dialogue Platform between Africa and Europe. Moreover, besides African governmental organizations, research institutions and NGOs, the involvement of a large number of African actors represented by prominent institutions operating in Africa ensures a mostly extensive coverage of the African continent. The project started in October 2016 and is planned to be completed in September 2019.

Fig. 1 Mortality rate (fatalities/100,000 population) per region, WHO 2015.

In order to improve road safety performance in African countries, many barriers need to be overcome. Among them stands the substantial lack of detailed knowledge on road casualties in terms of their number as well as of the associated factors leading to road accidents or affecting their consequences. There is a serious lack of road safety data in African countries, and even when data are available [e.g. through the reports of WHO (2015), International Road Federation – IRF (2016), etc.], little is known about data collection systems, data definitions, etc.

Reliable and accurate data are a fundamental prerequisite to understand the magnitude of road safety problems in Africa and convince stakeholders to take certain actions. Reliable and accurate data are also needed to identify problems priority areas and mostly risk factors in order to formulate strategies, set targets and monitor performance.

The support of policy makers and stakeholders with evidence on critical risk factors, related actions and good practices drawn from high quality data consist a key objective of the SaferAfrica project.

Under this scope, the objective of the present paper is to provide a critical overview of the infrastructure risk factors in African countries that play a key role in the evolution of road accident fatalities. Such an analysis will allow the identification of priority areas for road safety actions and interventions; where at the same time special emphasis should be given on those with high road safety improvement potential.

2. Methodology

One of the most critical factors affecting road safety outcomes is road infrastructure and the roadside environment (e.g. road type, geometrical design, traffic control, lighting conditions, etc.) (Elvik et al., 2009). According to a study by Sobngwi - Tambekou et al. (2010), developing countries account for more than 85% of all road traffic deaths in the world. The same study reports that the estimated overall number of people killed per 100 million kilometres driven in Cameroon was 73, more than 35 times higher than on similar roads in the United States of America or Europe.

It is, therefore, obvious that infrastructure risk factors play a crucial role, especially in less developed countries where the road network is not particularly advanced.

On that purpose, both macroscopic (generic level) and microscopic (infrastructure element level) potential risk factors were examined and rather interesting conclusions were drawn.

In order to take into account geographic characteristics and potential road safety performance heterogeneity, the identification of infrastructure risk factors was classified also per region. Specifically, the African countries were divided in the following five regions (Table 1):

- Northern Africa
- Eastern Africa
- Southern Africa
- Western Africa
- Central Africa

Table 1. Countries consisting African regions.

Eastern Africa	Western Africa	Northern Africa	Central Africa	Southern Africa
Burundi	Benin	Algeria	Angola	Botswana
Comoros	Burkina Faso	Egypt	Cameroon	Lesotho
Djibouti	Cape Verde	Libya	Central African Republic	Namibia
Eritrea	Gambia	Morocco	Chad	South Africa
Ethiopia	Ghana	Sudan	Republic of the Congo	Swaziland
Kenya	Guinea	Tunisia	Democratic Republic of the Congo	
Madagascar	Guinea-Bissau		Equatorial Guinea	
Malawi	Cote d'Ivoire		Gabon	
Mauritius	Liberia		São Tomé and Príncipe	
Mozambique	Mali			
Rwanda	Mauritania			
Seychelles	Niger			
Somalia	Nigeria			
South Sudan	Senegal			
Tanzania	Sierra Leone			
Uganda	Togo			
Zambia				
Zimbabwe				

Statistical analyses were performed using fatality rates per population coming from the 2013 World Health Organisation international database, available for 54 African countries. It should also be highlighted that disaggregate fatality data by road type were not available for the vast majority of the African countries.

Due to data limitations and lack of detailed data, additional sources of information were sought such as African and international technical reports and international scientific papers.

3. Macroscopic infrastructure risk factors

This section provides an overview of the main results of the analyses performed concerning infrastructure risk factors. An effort was made that the performed macroscopic infrastructure risk factors analyses, besides being restricted solely at country level, cover the African regions as well.

3.1. Country level analyses

Almost all African countries have less than 200,000 km of road network. Libya was considered an outlier for the current analyses, since it has by far the highest fatality rate (over 700 fatalities per million population) combined with a relatively low road network size (less than 100,000 km). Therefore, taking also into consideration the inaccuracy of the data, Libya was omitted from further analysis.

The statistical regression revealed that a polynomial model has the best fit (Table 2), where the fatality rates come along substantially reduced as the square of paved roads increases (Figure 2).

Table 1. Polynomial regression analysis results per paved roads (dependent variable: fatality rates per million population). Note. * = indicates significance at 99% level. R^2 = 0.53.

Variables	Beta coefficient	Std. Error	p-value
Constant term	282.755	6.340	<0.001*
Paved Roads^2	-0.0147	0.00213	<0.001*

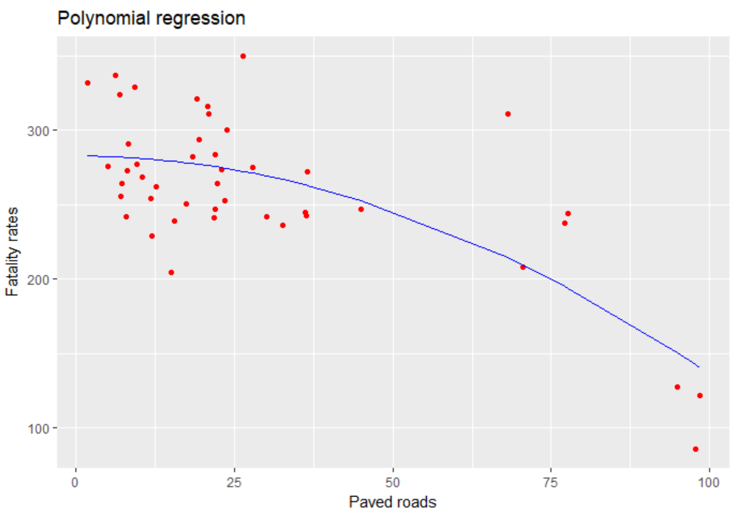

Fig. 2 Relationship between fatality rates per percentage of paved roads (polynomial model results).

Moreover, it was seen that the distribution of fatality rates per road network density has a declining trend as well. For this reason, polynomial regression analysis was also performed (Table 3), where it was found that as the square of road network density increases, fatality rates are somewhat reduced.

Table 2. Polynomial regression analysis results per road network density (dependent variable: fatality rates per million population). Note. * = indicates significance at 99% level. R^2 = 0.36.

Variables	Beta coefficient	Std. Error	p-value
Constant term	271.595	6.712	<0.001*
Road Network Density^2	-112.821	22.673	<0.001*

3.2. Geographic region analyses

It is interesting to note that there is no clear trend between road network and group of countries as the spread can be considered random. Only Libya (Northern region group) and South Africa (Southern region group) are considered as outliers as their characteristics are substantially different from the rest of the countries. On the other hand, as previously confirmed by the polynomial model, a non-linear declining trend is present regarding the impact of paved roads on fatality rates. Once again, there is no clear distinction among country groups. However, it can be observed that 4 Northern (Tunisia, Algeria, Egypt and Morocco) and 2 Eastern countries (Mauritius and Seychelles) are having a combination of high paved roads and low fatality rates. Lastly, when regarding road network density, most of groups have similar distributions, except for 2 Eastern countries (Mauritius and Seychelles) which have very low fatality rates (<200) but the highest road network densities.

The distribution of fatality rates per percentage of paved roads and road network density for each geographic region can be seen through Figure 3 and Figure 4 respectively.

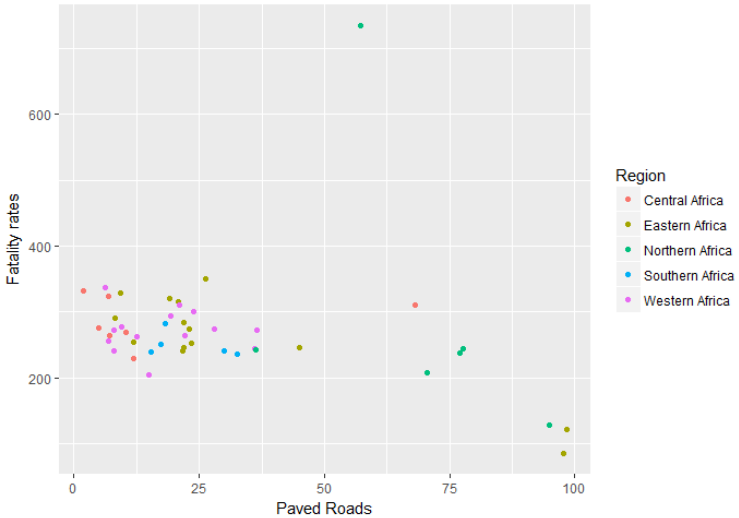

Fig. 3 Distribution of fatality rates per percentage of paved roads for each geographic region.

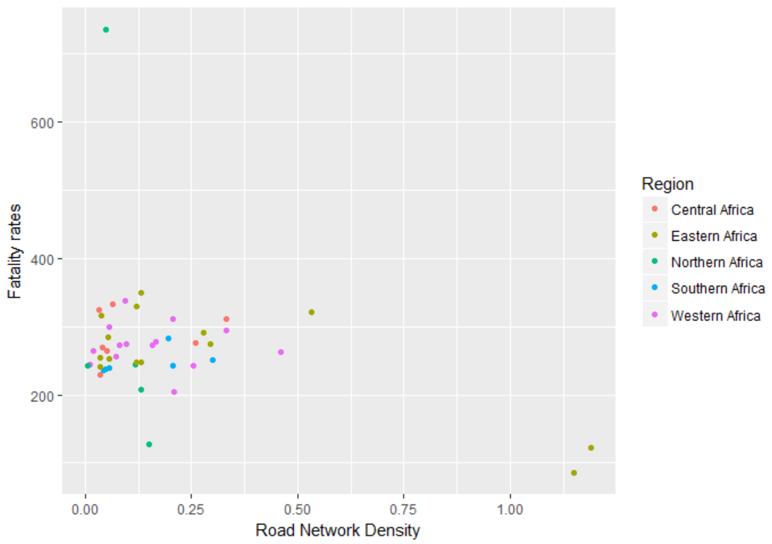

Fig. 4 Distribution of fatality rates per percentage of road network density for each geographic region.

4. Microscopic infrastructure risk factors

4.1. Technical report results

A technical report for the African Development Bank Group (2014), illustrates common infrastructure risk factors according to CaDaS as illustrated below:

- Type of roadway
- Road functional class
- Speed limit
- Road surface conditions
- Intersection
- Traffic control at intersection
- Road curve
- Road segment grade

These variables are common recorded crash data and are potential risk factors. Moreover, in the same report a comparison between Botswana and Great Britain, in terms of crash injury severity, suggested that Botswana has significantly higher severity attributed to poor passive safety (forgivingness) of road design. However, such a sugestion was mot confirmed through statistical validation (African Development Bank Group, 2014).

A previous technical report (United Nations-Economic Commission for Africa, 1989) focused on microscopic infrastructure risk factors, presented certain generic guidelines (i.e. causes and countermeasures to minimize crashes). For single-vehicle crashes the main road crash causes are: bad surface, steep gradients, narrow road, sharp bends, loose sand on the road and depression in road surface. For pedestrian crashes, the main common road crash causes are: undefined crossing sites, narrow road and lack of footpaths. Regarding multi-vehicle crashes, the following infrastructure risk factors are mentioned: a) for vehicles driving in the same direction (lack of turning lanes, restricted visibility at junctions, too short amber period at traffic light signals, lack of bus stops, damaged edges/potholes on the road, lack of proper signal indication), b) for vehicles driving at converging directions (steep gradients, junction lacking proper markings, short junction distances, minor junctions along main road, wrong timing of traffic light signals and c) for vehicles driving in opposite directions (sinkings of the pavement, short straight road section following a long hilly and curvy one, damaged edges/potholes and steep hills with slow heavy traffic). A similar drawback as in the aforementioned African Development Bank Group report is that there is no statistical validation of crash causes but only general guidelines. Other crash types are also considered and common infrastructure risk factors include inadequate sight distance, no warning triangle at a stopped vehicle, narrow road and inadequate bicycle/pedestrian facilities.

An interesting remark concerning the UN-ECA report is that 4 main categories of critical infrastructure risk factors (according to international studies) are specified, namely:

- Road alignment
- Road width
- Sight distance
- Road environment

For instance, in Figure 5 it can be seen that a radius of less than 500m can increase crash risk while one of 200m or less can cause significantly higher risk. With curve radii of approximately 600m the risk is about 1.5 accidents/10^8 veh.km, with radii of 400m about 2.0 crashes/10^8 veh.km and with radii of 100m 4.5 crashes/10^8 veh.km. Figure 6 shows the relationship of gradient and crash rates on the basis of international literature. On the other hand, Figure 7 depicts an established relationship between crash rates, sight distance and road width (no junctions are included).

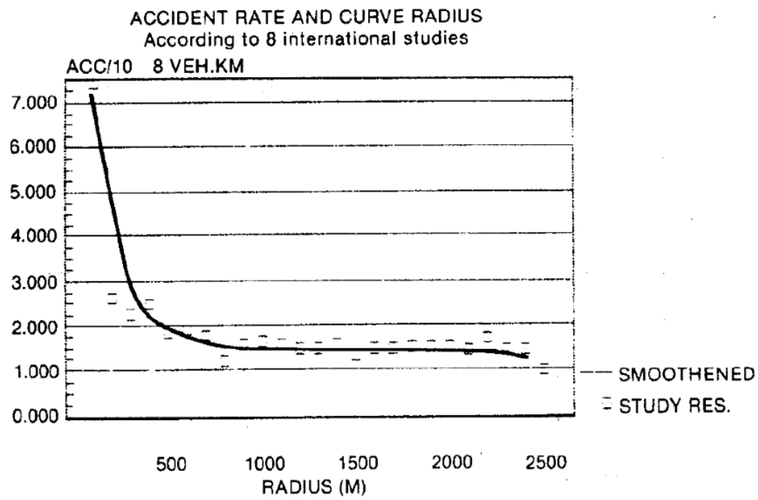

Fig. 5 Relationship between crash rates and curve radius. Source: United Nations-Economic Commission for Africa, 1989.

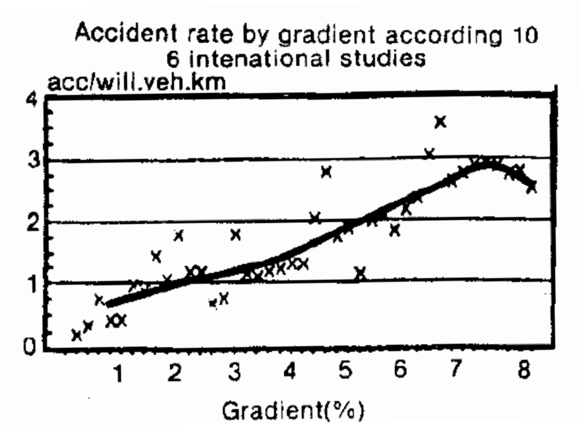

Fig. 6 Relationship between crash rates and gradient. Source: United Nations-Economic Commission for Africa, 1989.

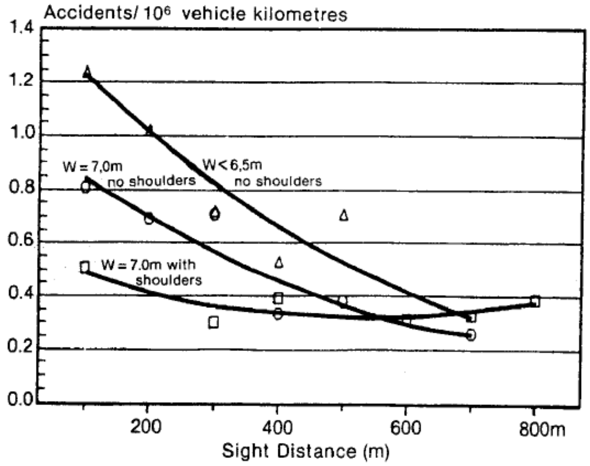

Fig. 7 Relationship between crash rates, sight distance and road width. Source: United Nations-Economic Commission for Africa, 1989.

According to the South African Road Traffic Signs Manual (2012), a desirable level of service is achieved when delays and stops are less than what might be regarded as tolerable or acceptable. In addition to the operational advantages of having an acceptable level of service, there is an important safety implication. Each stop has the potential of becoming an accident, while each second of excessive delay adds to driver frustration, which results in them taking risks, thus increasing the probability of collisions". Moreover, authors state that queue length provides an indication of the potential accident hazard of such a junction or crossing. As queues build and delay increases, drivers are more likely to take chances, increasing the risk of crashes.

A report from Tanzania (Road Geometric Design Manual, 2011) was prepared by the Ministry of Works for the design of roads in order to promote uniformity in design procedures in the country. A number of potential hazards when designing roads are discussed. For example, clear zone is considered as an important geometrical parameter. Many crashes involve drivers losing control of their vehicle, which then runs off the road and collides with a tree or other rigid object and overturns. The severity of these crashes can be reduced if the concept of the "forgiving roadside" is adopted, in which a clear zone is created. However, steep slopes can undermine the safety benefits of clear zones as it is suggested that "slopes steeper than 1:3 cannot be counted as part of the clear zone because they are too steep".

As mentioned in the UN-ECA (19890 report, road alignment is very critical. The Road Geometric Design Manual for Tanzania (2011) stresses the importance of consistent road alignment and suggest that abrupt changes in the road design standards could defy drivers' expectation and therefore, cause serious crashes. More specific risk factors (such as sight distance, lack of access control, absence of lighting etc.) are also discussed in that report and have similar impacts as previous reports. For instance, tangent sections have disadvantage of causing headlights glare and crashes due to fatigue and over speeding. Length of straights exceeding 2 kilometers is risky. On the other hand, short tangent sections between curves turning in the same direction could cause a "broken back" effect.

Junctions are very critical as well. Most of the intersection crashes occur at the very lightly trafficked at-grade intersections. From a traffic-safety aspect, these lightly trafficked intersections require as much attention as do those intersections where heavier conflicting traffic movements occur (Road Geometric Design Manual for Tanzania, 2011). The selection of priority intersection type should mainly be based on safety. The crossroads form of priority intersection is not recommended to be used as it has a very high number of conflict points and has a much higher crash risk than any other kind of intersection (Road Geometric Design Manual for Tanzania, 2011).

4.2. International published papers results

International published papers on microscopic infrastructure risk factors is not too extensive (similarly to macroscopic infrastructure risk factors). Abegaz et al. (2014) examined road crash injury severity. Data was collected from June 2012 to July 2013 on one of the main and busiest highway of Ethiopia, which extends from the capital, Addis Ababa, to Hawassa. Although they focused on drivers falling asleep as well as on excessive speeding, some other characteristics were also influential. Specifically, nighttime driving in the absence of street lights was classified as a potentially more serious injury outcome compared to driving at nighttime with the presence of street lights.

Bhatti et al. (2010) aimed to identify situational factors associated with road traffic crash sites on a heavy traffic 243 km road section in Cameroon by conducting a case-control study on Yaoundé - Douala road section. Results showed statistically significant associations with injury crash risk for flat road profile, irregular road surface conditions, roadside obstacles situated less than 4m from the road edge line, three-legged intersections and four-legged intersections. Furthermore, it was stated that built-up areas were significantly associated with injury crash sites where no verge was present.

South Africa has received much attention from researchers. Bester and Makunje (1994) describe the data and findings from 3 related studies in South Africa. The authors concluded that safety findings are consistent with international empirical findings, namely that decreased lane and shoulder widths lead to an increase in crash rates. A remarkable finding is that paved roads may not be beneficial for road safety. Another very interesting remark is that this study suggests that very long straight roads with low curvature rates may be riskier compared to slightly curved sections with curvature rates of approximately 40 degrees/km.

A more recent study by Das and Burger (2016) focused on appraisal of urban risk factors in South Africa. It is stated that road geometry variables such as number of access roads, median width and road width have an influence on the occurrence of traffic crashes to a certain extent. More specifically, as median width increases the number of crashes are reduced. On the other hand, the number of access roads as well as road width have a positive relationship with crash figures.

People's attitudes and perceptions towards infrastructure risk factors was also investigated by researchers and scholars. More specifically, Peltzer and Renner (2003) examined taxi drivers' superstition and risk perception of crashes in an urban area in South Africa. The perceived (subjective) causes of crashes were identified and included a number of infrastructure elements such as (ranked by relative importance from most to least important): lack of signals at junctions, bad condition of roads and traffic lights.

Vulnerable road users have received some attention as well. For example, Oluwadiya et al. (2009), focused on motorcycle injuries in Nigeria. Crash site characteristics such as road condition (tarred and smooth, tarred with potholes) and road layout (intersections, roundabouts, curved and straight sections) were discussed by means of descriptive statistics. 62.2% of injuries (299 in total) were reported at either long tangents or steep curves, and the remainder at junctions with or without roundabouts. 74% of pedestrian crashes occurred on curved or tangent road sections. Another remark is that the greater percentage of crashes at intersections occurred when motorcycles were turning right than when turning left.

Regarding pedestrian casualties, Liebenberg and Garrod (2005), analyzed national statistics from South Africa and reported the major infrastructure element-related risk factors: poor implementation of remedial measures in high risk locations and number of educational facilities.

5. Conclusions

The aim of the present paper was to provide a critical overview of the infrastructure risk factors in African countries. Both macroscopic (generic level) and microscopic (infrastructure element level) potential risk factors were examined and discussed.

Based on WHO mortality data, a macroscopic infrastructure risk factor analysis was carried out within the SaferAfrica project, showing a weak but existent relationship between extensive road network and fatality rates in African countries. More specifically, a strong declining trend was present when examining the relationship between fatality rates and percentage of paved roads. The same trend (but weaker) was identified when examining the impact of road network density on fatality rates per million population.

Regarding microscopic infrastructure risk factors, the main sources were technical reports and scientific papers, which revealed various potential factors, such as low road width, curve radius, low median width, absence of street light etc.

Although some research has been carried out on the field of infrastructure risk factors and road safety, the major identified drawback is the lack of data. This is concluded mainly because a lot of technical reports propose guidelines on the basis of international studies without having evaluated the suggested risk factors and countermeasures before. Therefore, it is strongly suggested to move towards this direction, i.e. validating empirical findings with real-African data. A decent attempt is recently made by researchers and scholars, as some high quality scientific papers have been identified.

Lastly, vulnerable road users (motorcyclists, pedestrians, children etc) have not received high attention so far, thus, it is suggested that future studies in Africa should also have specific focus on this category of road users.

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