2024 Road Safety & Simulation Conference
Improving Decisions Through Safety and Simulation Tools
Lexington, KY, USA
October 28-31, 2024

Leveraging Technology for Safer Roads for Vulnerable Road Users in South Africa

Ntombifuthi Ngobeni[1], Busisiwe Marole, Koketso Bosilong, Hlulani Nkuna

Smart Mobility, CSIR, PO Box 395, Pretoria, 0001, nngobeni1@csir.co.za
Smart Mobility, CSIR, PO Box 395, Pretoria, 0001, bmarole@csir.co.za
Smart Mobility, CSIR, PO Box 395, Pretoria, 0001, kbosilong@csir.co.za
Smart Mobility, CSIR, PO Box 395, Pretoria, 0001, hnkuna@csir.co.za

Abstract

This research aims to enhance road safety, particularly for Vulnerable Road Users (VRUs) such as pedestrians and cyclists, through the use of both cutting-edge technologies and consideration of conventional engineering methods and solutions. The study focuses on innovative solutions related to the road environment and their impact on VRU safety, piloted at selected sites in South Africa.

The research investigates the use of technologies such as video cameras, video analysis software, artificial intelligence and machine learning to conduct route risk assessments. These assessments inform the selection and implementation of effective safety measures tailored to enhance VRU safety. By understanding the unique challenges faced by these users, targeted interventions are developed through various modeling techniques.

The methodology involves conducting a pilot study, which includes the collection of extensive video data from South African roads. This data is crucial for examining the impact of various road environment factors and other factors on VRU safety.

The pilot study emphasises establishing appropriate route risk criteria, accurately collecting and analysing video data from the pilot sites and recommending safety measures based on the criteria that directly influence VRUs safety. These measures provide deep insights into the factors contributing to crashes and facilitate the evaluation of targeted road safety interventions. Through detailed collection and analysis, the study uncovers the root causes of accidents and other safety concerns involving VRUs.

This paper presents the findings from the pilot research study, which involved rigorous testing and evaluation to develop evidence-based solutions that address the specific needs of VRUs in South Africa. By leveraging technology and simulation tools, this research contributes to smarter decision-making in VRU road safety. Sharing our findings, we aim to support South African efforts in reducing road accidents and creating safer road environments for all users, particularly the most vulnerable.

Keywords: Vulnerable Road Users (VRUs); Road Safety, Route Risk Assessment.

[1] * Ntombifuthi Ngobeni. Tel.: +27-83-700-7476;
E-mail address: nngobeni1@csir.co.za

1. Introduction

Road safety remains a critical issue worldwide (World Health Organization, 2023), and South Africa is no exception. With high rates of road traffic accidents and fatalities, particularly involving VRUs such as pedestrians, cyclists, and school children (SaferSpaces, 2023), there is a pressing need for innovative solutions to enhance road safety. Traditional road infrastructure, primarily designed for vehicular traffic, often fails to address the unique challenges faced by these vulnerable groups. Consequently, a significant number of accidents and fatalities occur, underscoring the urgent need for effective interventions (SaferSpaces, 2023; OUTA, 2023).

Risk perception plays a significant role in influencing road safety across different socioeconomic and cultural contexts. It refers to an individual's subjective judgment about the severity and likelihood of risks in various traffic situations (Deery, 1999). In high-income countries such as Norway and the United States, road users generally experience well-developed infrastructure. This factor, amongst others contribute to a lower perception of risk (Şimşekoğlu et al., 2012). In contrast, road users in low- and middle-income countries (LMICs), including South Africa, often navigate less regulated and riskier environments. Poor road conditions and lack of pedestrian-friendly spaces increase their vulnerability. VRUs are disproportionately affected, as they face inadequate infrastructure and insufficient safety measures (Mohan, 2002). Studies have shown that the risk perception in LMICs tends to be higher than in high-income countries due to the hazardous traffic conditions and the lack of formal road safety interventions (Şimşekoğlu et al., 2012).

This research addresses the heightened risk perception that results from inadequate road environments and infrastructure in South Africa by analyzing localised data. It builds on existing literature, such as studies by Peden et al. (2004), which emphasize the importance of understanding road risk factors in context. For example, Zhang et al. (2020) identified geographical and spatial factors that contribute to traffic accidents, highlighting that the impact of road infrastructure varies depending on environmental and social contexts. This study integrates these findings into the South African context by focusing on localised VRU challenges and developing data-driven interventions through video analysis. These methods provide new insights into road risk factors and help facilitate the implementation of targeted, context-specific interventions. While global best practices offer valuable guidance, solutions must be adapted to address the specific risks that South African road users face, particularly by improving road infrastructure and addressing environmental risk factors.

In South Africa, the road environment is characterized by various risk factors, including poor road maintenance, inadequate lighting, and the presence of stray animals. Poorly maintained roads significantly contribute to the hazardous conditions faced by road users. The extensive backlog in road maintenance, estimated to be over R420 billion, leads to issues such as potholes, uneven surfaces, and inadequate signage, which exacerbate the risk of accidents (LeafySpace, 2023; Automobile Association, 2023). Inadequate lighting on South African roads is another critical factor that reduces visibility and increases the risk of accidents, especially at night. Proper lighting is essential for ensuring that drivers can see pedestrians and other obstacles, but many roads lack sufficient illumination (South African Road Federation, 2023). Additionally, the presence of stray animals on roads, particularly in rural areas, poses a significant threat to road safety. These animals can cause sudden hazards for drivers, leading to accidents involving both vehicles and VRUs (SaferSpaces, 2023).

The National Road Safety Strategy (NRSS) 2016-2030 emphasizes the importance of creating safe road environments by using innovative technologies to protect all road users (DoT, 2016)

Section 2 of this paper outlines the methodology, covering the data collection and analysis techniques used. Section 3 presents the results and analysis, focusing on road environment risk factors. Section 4 discusses the implications of these findings, while Section 5 concludes the paper with recommendations for future research and interventions.

2. Methodology

The flowchart in Figure 1 outlines the key steps followed in this study. It began with the design of the pilot study, where objectives were set to enhance road safety for Vulnerable Road Users (VRUs). A literature review and desktop study then identified key risk factors and routes. Video data was collected along identified routes. Machine learning techniques were used to analyse road risks. The study then identified patterns, leading to tailored recommendations aimed at improving safety on these selected routes.

Figure 1: Methodology

2.1. Route Risk Factors

The National Road Safety Strategy (NRSS) 2016 - 2030 was developed to enhance road safety for all road users by decreasing road fatalities and injuries due to crashes. The NRSS is preceded by previous road safety strategies that were also published for the South African context since 1996. The NRSS highlights the road environment factors, vehicle factors and human factors as the main contributing factors to fatal crashes. For the purpose of this study, the environment factors were considered as they have a major impact on VRUs' road safety.

Figure 2 below shows the road environment factors that contribute to fatal crashes and their percentage contribution. VRUs account for approximately 40% of these fatal crashes (DoT, 2016). The ranking of the highest contributing factors to the lowest can be determined from the percentages.

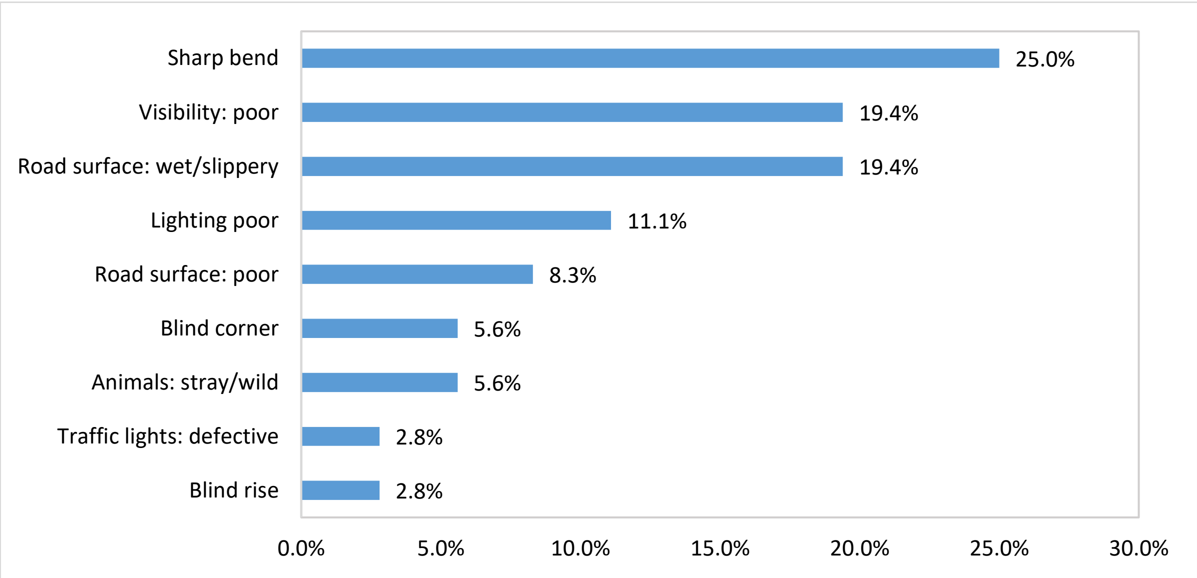

Figure 2: Road environment factors leading to fatal crashes (RTMC, 2014, cited in DoT, 2016)

If a road consists of one or more of these factors, the risk level of that road can be quantified according to the cumulative sum of the percentage contributions of the road environment factors thereof. The data served as a benchmark for measuring the risk level of the roads. The road environment factors identified from the video data collected for the different roads was analysed to produce the profiles of the road pertaining to road safety.

2.2. Video Data Collection

The approach to identifying dangerous locations and associated road safety risks involved using background knowledge published by the South African Road Accident Fund in December 2021 during the COVID-19 pandemic. This publication highlighted the top ten most dangerous roads in South Africa, which were located in six out of the nine provinces of the country. To further understand the characteristics of the identified routes that make them dangerous, some desktop studies were performed that provided information about the road locations, land use alongside the roads, typical weather conditions and more. Characteristics contributing to the danger of these roads were also sourced from previous studies and literature.

A team of researchers and data capturers were deployed to drive along selected routes for the pilot study. Their vehicle was instrumented with front-facing, rear-facing, left-facing, right-facing, and driver-facing cameras to capture video data of the road environment and driver behavior. This setup allowed comprehensive observation of the road environment the team was navigating.

Five data collection locations were chosen based on previous studies and accident reports identifying dangerous roads. These routes included highways and urban roads passing through various towns and villages with different land-use activities. Data collection aimed to capture a wide range of conditions, including different times of day and weather conditions. The vehicle used for data collection was equipped with cameras to capture footage of the road environment.

2.3. Video Data Analysis

The analysis of video data is a crucial component in understanding the real-world conditions and behaviors that contribute to road safety risks for VRUs. This section outlines the methodology and findings from the video data analysis, which provides insights into the interactions between vehicles and the road environment, and impact thereof of VRUs.

Collected video data was analysed using two qualitative and quantitative analysis software. The list of route risk factors in **Error! Reference source not found.** above were used as the coding metric in the software. The video analysis software was used to record each point in the road section where any of the route risk factors were identified. Although the length of the routes varied, for the purpose of the analysis, the video duration that was used to analyze each video was consecutive 30-minute cycles. The analysis focused on identifying patterns and trends that could inform targeted interventions to improve road safety for VRUs.

3. Analysis and Results

The video data underwent a thorough examination using two different types of machine learning techniques designed to identify and categorize various road environment risk factors.

The first one focused mainly on the route risk factors prescribed in the NRSS as road environment factors which are as follows:

- Sharp bend
- Poor visibility
- Wet/slippery road surface
- Poor lighting
- Poor road surface
- Blind corner
- Stray/wild animals
- Defective traffic lights
- Blind rise

Table 1 below shows the results of the video data analysis of the identified route risk factors along the five routes travelled for the video data capturing. The pilot study highway routes vary in km lengths, however for the purpose of the pilot study, each route's video was analysed for a consecutive 30-minute durations to identify the road environment risks.

Table 1: Pilot Route Risk Profiles

Road Environment Risk factors	**Pilot study routes**				
	Kokstad to Mthatha	Mhlanga to Mgababa	Pietermaritzburg to Umhlanga	Port Shepstone to Kokstad	Thongathi to Mhlanga
Sharp Bend/Curve (25%)	X	-	X	X	-
Poor Visibility (19.4%)	X	-	-	X	-
Wet/Slippery road (19.4%)	X	-	-	X	-
Poor Lighting (11.1%)	X	-	X	X	-
Poor road surface (8.3%)	X	-	X	-	-
Blind corner (5.6%)	-	-	-	X	-
Stray/wild animals (5.6%)	-	-	-	-	-
Defective traffic lights (2.8%)	-	-	-	X	-
Blind rise (2.8%)	-	-	X	X	-
Road safety profile (Total)	**83.2%**	**0%**	**47.2%**	**86.1%**	**0%**

Table 1 shows the route that had the highest risk profile based on the road safety contributory factor percentages was between Port Shepstone to Kokstad with a cumulative percentage of 86.1%, followed by the route between Kokstad to Mthatha with a cumulative percentage of 83.2%. The two routes that had no road environment risk factors identified were Mhlanga to Mgababa and Thongathi to Mhlanga. The results of the pilot study demonstrate the practicality of conducting the route risk assessment using the video data, rather than providing an accurate road safety profile of the pilot study routes. An extensive route risk assessment that covers the entire stretch of the highway route would be more accurate.

Factors such as "Poor Visibility" and "Wet/slippery road" can be temporal road environment risk factors of a road section because they are dependent on the incidents of the road at that specific time of recording (i.e., bad weather conditions, nighttime). Another factor that is temporal is the "Stray/wild animals" due to the movement of animals near a particular road section because they may not always stay in one location.

The second machine learning analysis tool focused on identifying mobile route risk factors. The video analysis results are summarised in **Figure 3** below, which illustrates the distribution of detected objects across different classes. The data shows that cars and other unspecified objects were the most frequently detected road users.

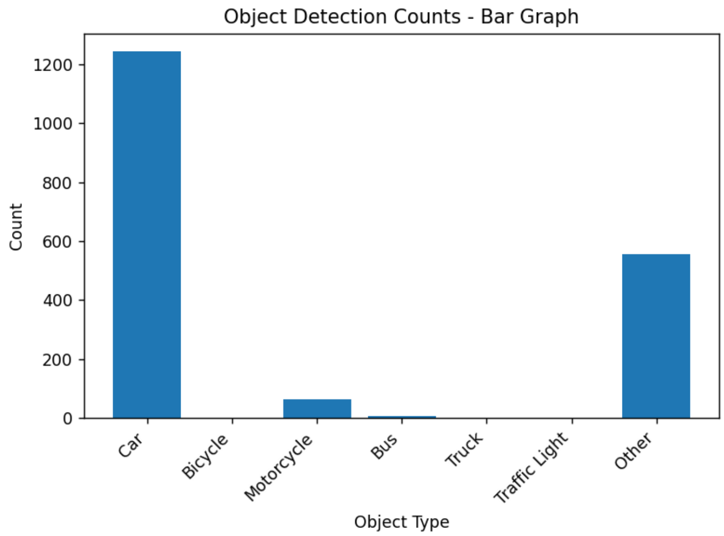

Figure 3: Object Detection Counts

The analysis revealed a predominant presence of vehicles, especially cars, which underscored the high vehicular traffic in the studied areas. Despite the lower detection rates of bicycles and motorcycles, their presence highlighted the need for dedicated safety measures. Buses and trucks were less frequently recorded, which may point to either their reduced presence during peak data collection times or a potential oversight in capturing data during their peak operational times.

4. Discussion

The findings from this study highlight the urgent need for targeted road safety interventions that address infrastructure deficiencies to enhance the safety of VRUs in South Africa. The comprehensive video data analysis identified several key route risk factors and provided a foundation for recommending specific safety measures.

The analysis of video data revealed several infrastructure shortcomings contributing to road safety risks. These included sharp bends, poor visibility, wet/slippery road surfaces, inadequate lighting, poor road surfaces, blind corners, and the presence of stray/wild animals. These factors were prevalent across different routes, with Port Shepstone to Kokstad and Kokstad to Mthatha showing the highest cumulative risk profiles at 86.1% and 83.2%, respectively.

Improving lighting is a critical measure to enhance visibility and reduce nighttime accidents. Installing sufficient and well-maintained lighting can mitigate these risks, ensuring that VRUs are visible to drivers at all times.

Dedicated spaces for pedestrians and cyclists, such as sidewalks and bike lanes, are essential for protecting VRUs. The lack of these facilities leads pedestrians and cyclists to share the road with motor vehicles, increasing their exposure to accidents (SaferSpaces, 2023). The National Road Safety Action Plan 2023-25 highlights the importance of prioritizing such infrastructure improvements, especially in high-risk areas, to create safer and more equitable road environments for all users (National Road Safety Action Plan, 2023). Similarly, the Global Plan for the Decade of Action for Road Safety 2021-2030 advocates for a Safe System approach, emphasizing the need for comprehensive road infrastructure improvements (Global Plan for Road Safety, 2021).

While infrastructure improvements are crucial, addressing driver behaviour is equally important. The analysis indicated high vehicular traffic, with cars being the most frequently detected road users, emphasizing the need for behavioural interventions. Public awareness campaigns can educate drivers on the importance of safe driving practices, particularly in areas with high pedestrian and cyclist traffic. These campaigns should focus on the importance of yielding to VRUs, and the need for vigilance in adverse weather conditions.

Enforcement of traffic laws plays a pivotal role in mitigating risky driver behaviours. Enhanced law enforcement presence on high-risk routes can act as a deterrent to reckless driving, thereby protecting VRUs.

The use of advanced technologies such as video analysis software, artificial intelligence, and machine learning to assess route risks and identify hazardous conditions offers significant potential. These technologies can provide real-time data and insights, allowing for timely interventions and informed decision-making. For instance, AI-driven systems can predict high-risk scenarios based on current road conditions and historical data, enabling pre-emptive measures to prevent accidents.

In line with the findings of this study, research on road safety interventions in school zones across Ghana, Vietnam, and Mexico demonstrated a significant reduction in pedestrian-vehicle conflicts following the implementation of targeted infrastructure improvements. These interventions included speed humps, pedestrian crossings, and enhanced signage, all of which led to measurable improvements in road safety. The study used Traffic Conflict Techniques (TCTs) to assess the impact of these interventions and confirmed that data-driven approaches can effectively reduce the risk of crashes involving vulnerable road users (Swanson et al., 2022). This aligns with the need for similar evidence-based interventions in South Africa, particularly for vulnerable road users (VRUs) in high-risk environments, as highlighted by this research.

Based on the analysis, the following safety measures are recommended:

Table 2: Safety Measures Recommendations

Safety Measures Recommendations	
Sharp Bend	Install more traffic calming infrastructure such as rumble strips.
	Provide Advisory speed
	Visible Sharp curve chevron
	Sharp curve warning sign.
Poor Visibility	Improve the retro-reflective material on road markings and signage.
	Reduce roadside vegetation.
Wet/Slippery Road Surface	Improve stormwater drainage.
	Enhance road pavement friction by using larger aggregate sizes.
	Utilize porous pavement material
Poor Lighting	Installation of new streetlights and maintenance of existing streetlights.
Poor Road Surface	Conduct regular road pavement maintenance.
	Rebuild severely damaged roads.
Blind Corner	Reduce blind spot by adding convex mirrors.
	Removable obstruction (e.g. vegetation, road furniture, etc.)
Stray/Wild Animals	Install fencing along roadsides.
	Build animal/VRU bridges.
	Install adequate warning road signage.
	Install traffic calming features.
Defective Traffic Lights	Conduct routine maintenance.
Blind Rise	Widen roads where possible, if not possible, install “No Over-taking” signage
	Install raised median.
Bicycle Detection	Implement dedicated bike lanes and cyclist signals.
	Conduct studies to assess the impact of cyclist behaviour on accident rates.
Car Detection	Monitor traffic flow and density to identify accident-prone areas.
	Implement measures to address speeding and erratic driving behaviour.
Motorcycle Detection	Study interactions between motorcycles and larger vehicles.
	Assess the effectiveness of motorcycle lanes or safety campaigns.
	Identify dangerous riding behaviours contributing to accidents.
Bus Detection	Analyse the impact of buses on traffic flow and safety.
	Evaluate the safety of bus stops and routes.
	Monitor compliance with bus lane rules.
Truck Detection	Assess the impact of heavy vehicles on road safety.
	Study accident patterns involving trucks.
	Implement measures to improve truck safety, such as better signage or restricted hours.
Traffic Light Detection	Monitor traffic signal compliance.
	Analyse the effectiveness of traffic light timings on accident rates.
	Implement adaptive traffic signal systems to improve safety.

5. Conclusions

There is a critical need for a comprehensive approach to enhancing road safety for VRUs in South Africa. Our route risk assessment and video data analysis have identified several key risk factors that contribute to road accidents involving VRUs. These findings highlight the importance of targeted interventions that combine both conventional engineering methods and advanced technological solutions.

Improving road infrastructure such as installing adequate street lighting, enhancing road maintenance, and creating dedicated spaces for pedestrians and cyclists can significantly reduce the risk factors identified. Additionally, public awareness campaigns and stringent enforcement of traffic laws are crucial to mitigating risky driver behaviors and fostering a safer road environment. Technological integration, including the use of video analysis software, artificial intelligence, and machine learning, offers valuable real-time insights that can inform timely and effective interventions. These measures, along with considering the broader socioeconomic context, can create a safer and more equitable road environment for all users, particularly VRUs.

Future Work

Our research team will undertake several initiatives to build on the findings of this study and further enhance road safety for VRUs:

- Integration of Emerging Technologies

We plan to explore the integration of emerging technologies such as vehicle to infrastructure communication and smart infrastructure.

- Expanded Route Risk Assessments and focus on Risk Perception

We will conduct longitudinal studies across a broader range of road conditions and geographic areas to monitor the effectiveness of implemented interventions over time. These assessments will look more intently and extensively at risk perception, focusing on how road users assess and respond to various risks in different contexts. Understanding shifts in risk perception will help inform more precise, data-driven interventions that target both the actual and perceived dangers on South African roads.

Acknowledgment

We would like to extend our deepest gratitude to the following individuals for their invaluable contributions to this research: Lydia Kwange, Khangwelo Muronga, Karien Venter, Philip Mashaba, Boniswa Mashaba, Tebogo Matsaung, Tshegofatso Mongae, Thendo Malima and Andy Sejake.

Without their dedication and collaborative efforts, the successful completion of this research and the writing of this paper would not have been possible. Thank you for your hard work and commitment to enhancing road safety for VRUs in South Africa.

References

1. World Health Organization, Global status report on road safety 2023, 2023. https://iris.who.int/bitstream/handle/10665/375016/9789240086517-eng.pdf?sequence=1
2. SaferSpaces, Road Safety in the South African Context, 2023. Available at: https://www.saferspaces.org.za/understand/entry/road-safety-in-the-south-african-context
3. OUTA, Road safety is a colossal South African concern: what's the plan, government?, 2023. Available at: https://www.outa.co.za/articles/road-safety-south-africa
4. Deery, H. A. (1999). Hazard and risk perception among young novice drivers. Journal of Safety Research, 30(4), 225-236. Available at: Hazard and Risk Perception among Young Novice Drivers - ScienceDirect
5. Şimşekoğlu, Ö., Nordfjærn, T., & Rundmo, T. (2012). Traffic risk perception, road safety attitudes, and behaviors among road users: a comparison of Turkey and Norway. Journal of Risk Research, 15(7), 787-800. Available at: https://doi.org/10.1080/13669877.2012.657221
6. Mohan, D., (2002). Road safety in less-motorized environments: future concerns. International Journal of Epidemiology. Available at: https://doi.org/10.1093/ije/31.3.527
7. Peden, M., Scurfield, R., Sleet, D., Mohan, D., Hyder, A. A., Jarawan, E., & Mathers, C. (2004). World report on road traffic injury prevention. World Health Organization. Available at: https://www.who.int/publications/i/item/world-report-on-road-traffic-injury-prevention
8. Zhang, Y., Lu, H., & Qu, W. (2020). Geographical detection of traffic accidents: Spatial stratified heterogeneity and influence factors. International Journal of Environmental Research and Public Health. Available at: https://www.mdpi.com/1660-4601/17/2/572
9. LeafySpace, The Challenges Facing Road Maintenance in SA and Finding the Right Solutions to Them, 2023. Available at: https://leafyspace.co.za/the-challenges-facing-road-maintenance-in-sa-and-finding-the-right-solutions-to-them/
10. Automobile Association, Poor infrastructure equals poor road safety, 2023 Available at: https://aa.co.za/poor-infrastructure-equals-poor-road-safety/
11. South African Road Federation, Lack of road maintenance in SA will cost SA billions of Rands, 2023. Available at: https://sarf.org.za/lack-of-road-maintenance-in-sa-will-cost-sa-billions-of-rands/
12. Department of Transport, National Road Safety Strategy 2016-2030, 2016. Available at: https://www.gov.za/sites/default/files/gcis_document/201708/strategicplansnationalroadsafetystrategy2016to2030.pdf
13. National Road Safety Action Plan 2023–25, 2023. Australian Government. Available at: https://www.roadsafety.gov.au/sites/default/files/documents/National%20Road%20Safety%20Action%20Plan%202023-25_0.pdf
14. Global Plan for the Decade of Action for Road Safety 2021-2030. (2021). World Health Organization. Available at: https://cdn.who.int/media/docs/default-source/documents/health-topics/road-traffic-injuries/global-plan-for-road-safety.pdf?sfvrsn=65cf34c8_35&download=true
15. Swanson, J. M., Draisin, N., Krasnolucka, A., Vadillo, C., Medina, S., & Pérez, B., 2022. Observing pedestrian-vehicle traffic conflicts in school zones to evaluate the effectiveness of road safety interventions and reduce injuries in Ghana, Vietnam, and Mexico. Journal of Injury and Violence Research.