ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.939

Influence of Geometry on Accident Risk Levels. Application of the Predictive HSM Method on a Rural Road in Perú

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Abstract*— This study focuses on thoroughly examining how the geometric characteristics of rural roads in Peru impact safety, using the Highway Safety Manual (HSM) as the primary reference point. By adjusting the predictive HSM model to fit specific conditions, the most significant variables in anticipating road incidents were identified. Out of the 14 considered variables, three emerge as the most relevant in accident prediction. The presence of rumble strips, the Hazard Index in sections with obstacles and barriers account for 47.74% of relevance, while variables related to horizontal curves, such as length and radius, contribute with 18.35% importance in this predictive calculation. This study emphasizes the need to expand the database with information from other roads sharing similar characteristics. This would not only improve the accuracy of the calculation but also confirm the priority of the identified variables for all Second-Class Rural Roads. The results obtained highlight the influence of geometric aspects on the probability of accidents, thus supporting the need for specific improvements. This study underscores the importance of adapting the HSM to the specific conditions of each region in local rural roads. The presented results provide a solid foundation and concrete outcomes for decision-making in the planning and improvement of road safety in similar environments in Perú.

***Keywords*—Road Accidents, Highways, HSM, Road Geometry, Second-Class, Principal component analysis**

I. INTRODUCTION

The clear impact of each geometric element of the roadway on road safety has not been determined. Despite the evident relevance of road geometry to risk levels, the lack of a detailed and comprehensive analysis limits the ability to proactively address deficiencies in road design, thereby contributing to the ongoing increase in traffic accidents in the region. For instance, even with compliance with the Peruvian Design Standard (DG-2018), the design of horizontal curves on a Peruvian roadway may lead to risk situations not covered by current regulations. Limited visibility on these curves, combined with factors such as vehicle speed, could decrease drivers' perception of safety, increasing the likelihood of collisions and rollovers. The lack of a detailed understanding of these geometric factors impacts road safety, hindering the implementation of specific measures to mitigate these risks and, consequently, missing the opportunity to significantly improve safety on a Rural Roadway.

II. STATE OF THE ART

Road safety has been studied in various geographical contexts, and numerous research efforts have addressed the influence of road geometry on accident occurrence. Two studies highlight traffic speed and specific design features, such as lane count and curve radius, as significant influences on collision occurrence, emphasizing the importance of managing both factors [1,2]. The connection between reduced speed and improved traffic efficiency in mountainous areas was emphasized, indicating that speed reduction contributes to both safety and traffic flow efficiency [3]. Similarly, a study evaluates how certain roadway geometry design variables affect collision risk on highway segments with closely spaced entrance and exit ramps, emphasizing the importance of lane quantity and arrangement in collision risk [4]. Concerning design optimization to reduce specific risks, two studies examine excess accidents in areas with steep grades and roadway curvature, proposing alternative route designs that replace consecutive descents and ascents with continuous descent while maintaining minimum curve radii, aiming to reduce speed at critical points [5,6]. In this regard, one study analyzes factors influencing off-road crashes, highlighting the importance of traffic barriers and factors such as height and spacing between posts, proposing updates in policies and recommendations for their installation and improvement, specifically on curved segments [7]. Additionally, one study proposes the construction of new planimetric paths on tight curves, considering simultaneous entry of vehicles in opposite directions. This would ensure adequate safety distance at the curve crown, enhancing safety in these specific areas [8]. A group of researchers focused on improving safety evaluation on roads and the effectiveness of Road Safety Systems (RSS) on two-lane, two-way rural roads. This was done through a comparison with the predictive method from the road safety manual and safety performance focused on design coherence itself [9]. Meanwhile, another study utilizes a machine learning algorithm to relate latent geometry codes to traffic accidents, providing practical decision-making tools [10]. Similarly, some researchers propose an information model for operational road risk management, emphasizing the importance of communication and information exchange to enhance road safety [11]. In the technological realm, deficient obstacle recognition in adverse weather conditions was addressed through artificial vision technology [12,13], while another study examined the effectiveness of fog lights to improve visibility on foggy roads during the night [14]. Furthermore, the effectiveness of road lighting system replacement was evaluated [15]. These studies provide a solid foundation for understanding challenges and opportunities at the intersection of road geometry and safety, addressing specific aspects such as speed, geometric design, risk management, and technology integration.

In this research, an analysis is conducted on how road geometry affects risk levels on a Second-Class Rural Road stretch. The estimation of the calibration factor of the accident prediction module of the Highway Safety Manual (HSM) is carried out, allowing for a more precise evaluation of risks associated with road geometry. Unlike previous studies, this research does not solely identify deficiencies in road geometry but also evaluates the degree of influence of these elements concerning road safety [16].

III. METHODOLOGY

A. Flowchart

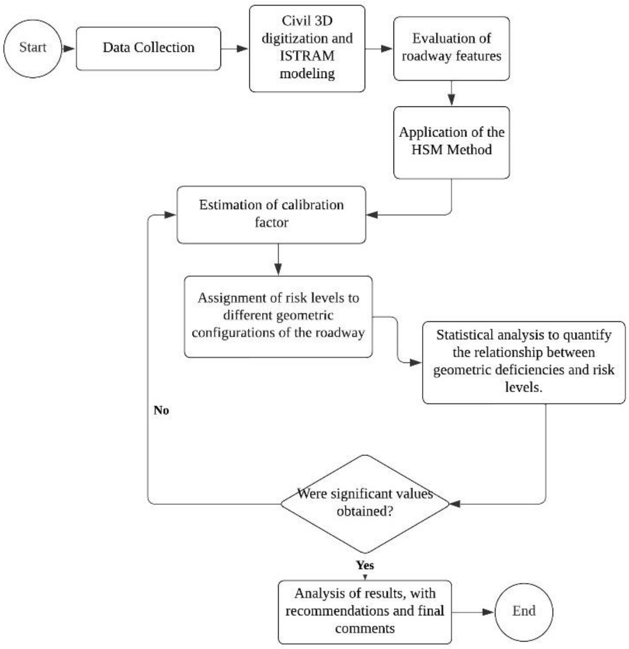


Fig. 1. Investigation process flowchart

As shown in the flowchart (see Fig. 1), the research began with data collection, where geospatial and geometric data of the Peruvian Rural Road were gathered. Subsequently, the HSM Method was applied in several steps: first, the current road situation was verified; second, the period of interest was established; third, the Annual Average Daily Traffic (AADT) was evaluated, and observed accidents in the analysis segment were examined; fourth and fifth, the geometric design characteristics were determined, and the transportation network was divided into specific segments and intersections. Subsequently, the Calibration Factor was estimated: accident modification factors were applied, and both the expected mean accident frequency (Npredicted) and observed (Nobserved) were calculated. Finally, the analysis of geometric elements was conducted to conclude the study.

B. Theoretical Framework

a. Herramientas y materiales

The study made reference to the Road Safety Manual 2017 to ensure consideration of specific aspects related to road safety. Additionally, reference was made to the Road Manual: Geometric Design (DG-2018) to ensure compliance with design regulations in Peru. The Geographic Information System (GIS) played a key role in spatial visualization of data and geometric elements. For geometric modeling, ISTRAM software was used, providing advanced capabilities for representation and design of road infrastructures. Additional geometric modeling tools, such as CIVIL 3D software, were also employed to address specific design aspects. Data collection and processing were supported by EXCEL software. The Highway Safety Manual (HSM) database was essential for evaluating risks associated with road geometry. Finally, statistical analysis was conducted using principal component analysis in Excel, providing a quantitative assessment of geometric factors and how these elements affect road safety.

C. Study Area

In this study, various tools and materials were employed to conduct a detailed analysis of the influence of road geometry on risk levels in a specific stretch of Second-Class Rural Road. The geographical delimitation of the analysis was carried out on a specific stretch of road in the northern part of the Lima department, covering regions of Lima, Pasco, and Huánuco, from the districts of Sayán to Churín, from km 80 to 86. For the estimation of accident frequency, the years 2020, 2021, 2022, and 2023 were considered.

D. Data collection

The data was obtained through a digital elevation model (DEM) from the Alaska geoserver (ASF DAAC) of NASA, which provides geospatial information free of charge. The DEM was acquired from the Alos Palsar satellite with a resolution of 12.5 meters per pixel. These data were imported in .TXT format and finally digitized in Civil 3D software, as depicted in Fig. 2, for subsequent use in the ISTRAM Modeling program to have more precise road-related data (see Fig. 3).

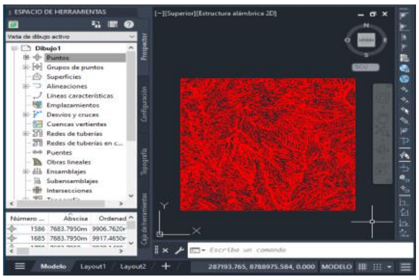


Fig. 2. Point digitization in Civil 3D

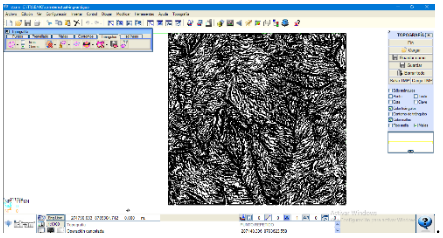


Fig. 3. Topography in ISTRAM

E. Aplicación del Método HSM

Step 1 and 2: Delimiting the area and assigning a study period of interest.

Four years of historical road accident records were analyzed since the study stretch consists of a road spanning over 3 kilometers. This time frame was selected because the Road Safety Manual identifies it as suitable for analysis.

Step 3: Determining the availability of annual traffic volumes, as shown in Table 1.

TABLE I. AADT BY YEARS

	AADT by years			
Year	2020	2021	2022	2023
AADT	457	470	484	499

The estimated accident frequency in the study stretch during the selected timeframe is calculated using the information provided in Table II.

TABLE II. ANNUAL TOTAL ACCIDENTS

Variables	Año			
	2020	**2021**	**2022**	**2023**
Annual Total Accidents	18	15	12	10

Steps 4 and 5: In the development process of the predictive method of the HSM, a fundamental step is the division of the road into homogeneous sections, taking into account the basic conditions of each segment, which encompass both geometric characteristics and the road environment. The total length of the road under analysis is 6 kilometers, and it has been divided into three segments of 2 kilometers each as part of the segmentation.

TABLE III. BASIC CONDITIONS OF THE SEGMENTS

Segment	Length		Roadway width		Number of accesses	Number of lanes	
	(m)	(Mi)	(m)	(Ft)		E	O
1	2000	1.243	6	19.685	2	2	2
2	2000	1.243	6	19.685	2	2	2
3	2000	1.243	6	19.685	2	2	2

Table IV presents the baseline characteristics of the roadway in each segment of interest, considering both geometry and traffic control; these values are relevant for calculating Accident Modification Factors (FMCs). [17]

TABLE IV. ROAD CONDITIONS

Segment	Parking	Lighting	Stationary objects	Median width		Automated Speed Control
				(m)	(Ft)	
1	No	No	No	0	0	No
2	No	No	No	0	0	No
3	No	No	No	0	0	No

- Estimation of Calibration Factor:

The accident prediction method of the HSM was applied, and the calibration factor for the study section was estimated. Parameters such as traffic volumes, road characteristics, and previous accident data were taken into account.

Step 6: The appropriate calibration factor was applied.

TABLE V. COMBINATION OF MODIFICATION FACTORS (FMC) FROM 2020 TO 2023

Segment	Station		Lane Width	Berm Width and Type	Horizontal Curves: Length, Radius	Horizontal Curves: Superelevation	Longitudinal Slope
	Start	End	FMC 1r	FMC 2r	FMC 3r	FMC 4r	FMC 5r
1	80+000	82+035.175	1.115	0.845	1.002	1.000	1.100
2	82+035.175	84+135.399	1.115	0.845	1.002	1.000	1.100
3	84+135.399	86+000	1.115	0.845	1.003	1.000	1.100

Access density	Centerline rumble strips	Passing lane	Left-turn lane
FMC 6r	FMC 7r	FMC 8r	FMC 9r
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

Hazard index d(RHR)	Lighting	Automated speed enforcement	Combination of FMC
FMC 10r	FMC 11r	FMC 12r	FMC s
1.143	0.922	1.000	1.094
1.306	0.922	1.000	1.250
1.222	0.922	1.000	1.170

Step 7: The empirical Bayes (EB) method was used to integrate the predicted mean accident frequency determined with the predictive model, Npredicted, and the observed, Nobserved.

TABLE VI. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2020

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	End		FMC s	C	Predicted N
1	80+000	82+035.175	0.152	1.094	1.000	0.166
2	82+035.175	84+135.399	0.152	1.250	1.000	0.190
3	84+135.399	86+000	0.152	1.170	1.000	0.178

TABLE VII. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2021

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	End		FMC s	C	Predicted N
1	80+000	82+035.175	0.156	1.094	1.000	0.171
2	82+035.175	84+135.399	0.156	1.250	1.000	0.195
3	84+135.399	86+000	0.156	1.170	1.000	0.183

TABLE VIII. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2022

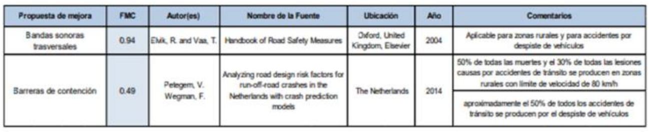
Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	End		FMC s	C	Predicted N
1	80+000	82+035.175	0.161	1.094	1.000	0.176
2	82+035.175	84+135.399	0.161	1.250	1.000	0.201
3	84+135.399	86+000	0.161	1.170	1.000	0.188

TABLE IX. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2023

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	End		FMC s	C	Predicted N
1	80+000	82+035.175	0.166	1.094	1.000	0.181
2	82+035.175	84+135.399	0.166	1.250	1.000	0.207
3	84+135.399	86+000	0.166	1.170	1.000	0.194

To perform the evaluation, a improvement proposal generated by the Accident Modification Factors (FMCs) is selected for the chosen segment, as it is used for the evaluation outlined in this study. Since the same roadway is studied, and thus the same situation, calculations are performed starting from step 6 of the study.

The Accident Modification Factors (FMCs) related to other improvement proposals are detailed in Figure 4.



Propuesta de mejora	FMC	Autor(es)	Nombre de la Fuente	Ubicación	Año	Comentarios
Bandas sonoras trasversales	0.94	Elvik, R. and Vaa, T.	Handbook of Road Safety Measures	Oxford, United Kingdom, Elsevier	2004	Aplicable para zonas rurales y para accidentes por despiste de vehículos
Barreras de contención	0.49	Petegem, V. Wegman, F.	Analyzing road design risk factors for run-off-road crashes in the Netherlands with crash prediction models	The Netherlands	2014	50% de todas las muertes y el 30% de todas las lesiones causas por accidentes de tránsito se producen en zonas rurales con límite de velocidad de 80 km/h aproximadamente el 50% de todos los accidentes de tránsito se producen por el despiste de vehículos

Fig. 4. Modification factors of other improvement alternatives

TABLE X. COMBINATION OF MODIFICATION FACTORS (FMC) FROM 2020 TO 2023

Segment	Station		Lane Width	Berm Width and Type	Horizontal Curves: Length, Radius	Horizontal Curves: Superelevation	Longitudinal Slope
	Start	End	FMC 1r	FMC 2r	FMC 3r	FMC 4r	FMC 5r
1	80+000	82+035.175	1.115	0.690	1.002	1.000	1.100
2	82+035.175	84+135.399	1.115	0.690	1.002	1.000	1.100
3	84+135.399	86+000	1.115	0.690	1.003	1.000	1.100

Access density	Centerline rumble strips	Passing lane	Left-turn lane
FMC 6r	**FMC 7r**	**FMC 8r**	**FMC 9r**
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

Hazard index d(RHR)	Lighting	Automated speed enforcement	Combination of FMC
FMC 10r	**FMC 11r**	**FMC 12r**	**FMC s**
1.143	0.922	1.000	0.893
1.306	0.922	1.000	1.021
1.222	0.922	1.000	0.955

TABLE XI. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2020

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	**End**		**FMC s**	**C**	**Predicted N**
1	80+000	82+035.175	0.152	0.893	1.000	0.136
2	82+035.175	84+135.399	0.152	1.021	1.000	0.155
3	84+135.399	86+000	0.152	0.955	1.000	0.145

TABLE XII. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2021

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	**End**		**FMC s**	**C**	**Predicted N**
1	80+000	82+035.175	0.156	0.893	1.000	0.139
2	82+035.175	84+135.399	0.156	1.021	1.000	0.159
3	84+135.399	86+000	0.156	0.955	1.000	0.149

TABLE XIII. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2022

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	**End**		**FMC s**	**C**	**Predicted N**
1	80+000	82+035.175	0.161	0.893	1.000	0.144
2	82+035.175	84+135.399	0.161	1.021	1.000	0.164
3	84+135.399	86+000	0.161	0.955	1.000	0.154

TABLE XIV. PREDICTED ACCIDENT FREQUENCY (N PREDICTED) IN 2023

Segment	Station		N FDS	FMC Combination	Calibration Facctor	Predicted Accident Frequency
	Start	**End**		**FMC s**	**C**	**Predicted N**
1	80+000	82+035.175	0.166	0.893	1.000	0.148
2	82+035.175	84+135.399	0.166	1.021	1.000	0.169
3	84+135.399	86+000	0.166	0.955	1.000	0.158

IV. RESULTS AND ANALYSIS

- Geometric Elements Analysis:

The evaluation assessed how each identified geometric element (curves, slopes, intersections) contributes to the risk of accidents in the area. Utilizing tools from the HSM to assign risk levels to different geometric configurations, according to the collected data.

TABLE XV. SUMMARY OF CALCULATIONS PERFORMED IN THE CURRENT ROAD CONDITION

Year	Predicted Accident Frequency
	Predicted N
2020	0.533
2021	0.548
2022	0.565
2023	0.582
TOTAL	**2.228**

TABLE XVI. SUMMARY OF CALCULATIONS PERFORMED IN ROAD STUDY PROPOSAL

Year	Predicted Accident Frequency
	Predicted N
2020	0.435
2021	0.448
2022	0.461
2023	0.475
TOTAL	**1.819**

- Statistical Analysis:

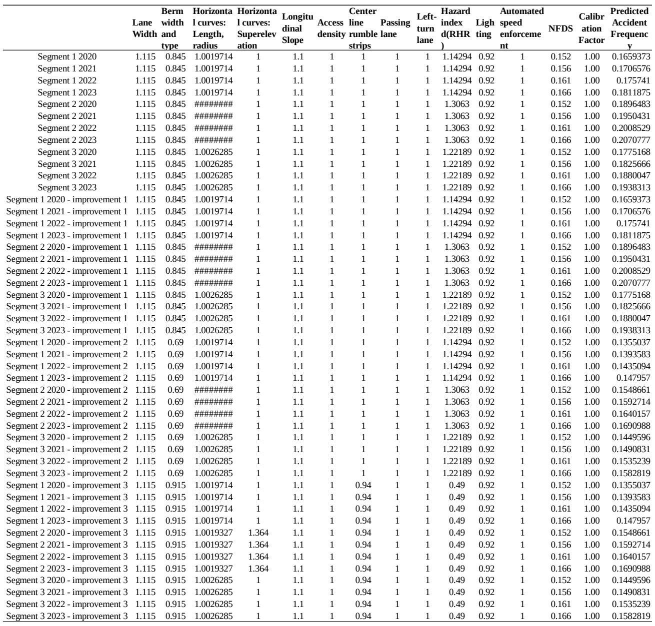
A statistical analysis was conducted to quantify the relationship between geometric deficiencies and risk levels. Principal component analysis was performed using Excel.

The evaluation was carried out by identifying the factors affecting the predicted accident frequency, as its calculation is executed using the following expression:

$$Npredicho = NFDS * (FMCs) * C$$

Therefore, the following values will be considered:

Lane width, Shoulder width and type, Horizontal curves: length, radius, and superelevation, Longitudinal slope, Access density, Centerline rumble strips, Passing lane, Left-turn lane, Hazard index, Lighting, and Automated speed enforcement. (see Fig. 5).



	Lane Width	Berm width and type	Horizontal curves: Length, radius	Horizontal curves: Superelevation	Longitudinal Slope	Access density	Center line rumble strips	Passing lane	Left-turn lane	Hazard index d(RHR)	Lighting	Automated speed enforcement	NFDS	Calibration Factor	Predicted Accident Frequency
Segment 1 2020	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.152	1.00	0.1659373
Segment 1 2021	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.156	1.00	0.1706576
Segment 1 2022	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.161	1.00	0.175741
Segment 1 2023	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.166	1.00	0.1811875
Segment 2 2020	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.152	1.00	0.1896483
Segment 2 2021	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.156	1.00	0.1950431
Segment 2 2022	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.161	1.00	0.2008529
Segment 2 2023	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.166	1.00	0.2070777
Segment 3 2020	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.152	1.00	0.1775168
Segment 3 2021	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.156	1.00	0.1825666
Segment 3 2022	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.161	1.00	0.1880047
Segment 3 2023	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.166	1.00	0.1938313
Segment 1 2020 - improvement 1	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.152	1.00	0.1659373
Segment 1 2021 - improvement 1	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.156	1.00	0.1706576
Segment 1 2022 - improvement 1	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.161	1.00	0.175741
Segment 1 2023 - improvement 1	1.115	0.845	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.166	1.00	0.1811875
Segment 2 2020 - improvement 1	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.152	1.00	0.1896483
Segment 2 2021 - improvement 1	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.156	1.00	0.1950431
Segment 2 2022 - improvement 1	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.161	1.00	0.2008529
Segment 2 2023 - improvement 1	1.115	0.845	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.166	1.00	0.2070777
Segment 3 2020 - improvement 1	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.152	1.00	0.1775168
Segment 3 2021 - improvement 1	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.156	1.00	0.1825666
Segment 3 2022 - improvement 1	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.161	1.00	0.1880047
Segment 3 2023 - improvement 1	1.115	0.845	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.166	1.00	0.1938313
Segment 1 2020 - improvement 2	1.115	0.69	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.152	1.00	0.1355037
Segment 1 2021 - improvement 2	1.115	0.69	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.156	1.00	0.1393583
Segment 1 2022 - improvement 2	1.115	0.69	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.161	1.00	0.1435094
Segment 1 2023 - improvement 2	1.115	0.69	1.0019714	1	1.1	1	1	1	1	1.14294	0.92	1	0.166	1.00	0.147957
Segment 2 2020 - improvement 2	1.115	0.69	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.152	1.00	0.1548661
Segment 2 2021 - improvement 2	1.115	0.69	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.156	1.00	0.1592714
Segment 2 2022 - improvement 2	1.115	0.69	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.161	1.00	0.1640157
Segment 2 2023 - improvement 2	1.115	0.69	########	1	1.1	1	1	1	1	1.3063	0.92	1	0.166	1.00	0.1690988
Segment 3 2020 - improvement 2	1.115	0.69	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.152	1.00	0.1449596
Segment 3 2021 - improvement 2	1.115	0.69	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.156	1.00	0.1490831
Segment 3 2022 - improvement 2	1.115	0.69	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.161	1.00	0.1535239
Segment 3 2023 - improvement 2	1.115	0.69	1.0026285	1	1.1	1	1	1	1	1.22189	0.92	1	0.166	1.00	0.1582819
Segment 1 2020 - improvement 3	1.115	0.915	1.0019714	1	1.1	1	0.94	1	1	0.49	0.92	1	0.152	1.00	0.1355037
Segment 1 2021 - improvement 3	1.115	0.915	1.0019714	1	1.1	1	0.94	1	1	0.49	0.92	1	0.156	1.00	0.1393583
Segment 1 2022 - improvement 3	1.115	0.915	1.0019714	1	1.1	1	0.94	1	1	0.49	0.92	1	0.161	1.00	0.1435094
Segment 1 2023 - improvement 3	1.115	0.915	1.0019714	1	1.1	1	0.94	1	1	0.49	0.92	1	0.166	1.00	0.147957
Segment 2 2020 - improvement 3	1.115	0.915	1.0019327	1.364	1.1	1	0.94	1	1	0.49	0.92	1	0.152	1.00	0.1548661
Segment 2 2021 - improvement 3	1.115	0.915	1.0019327	1.364	1.1	1	0.94	1	1	0.49	0.92	1	0.156	1.00	0.1592714
Segment 2 2022 - improvement 3	1.115	0.915	1.0019327	1.364	1.1	1	0.94	1	1	0.49	0.92	1	0.161	1.00	0.1640157
Segment 2 2023 - improvement 3	1.115	0.915	1.0019327	1.364	1.1	1	0.94	1	1	0.49	0.92	1	0.166	1.00	0.1690988
Segment 3 2020 - improvement 3	1.115	0.915	1.0026285	1	1.1	1	0.94	1	1	0.49	0.92	1	0.152	1.00	0.1449596
Segment 3 2021 - improvement 3	1.115	0.915	1.0026285	1	1.1	1	0.94	1	1	0.49	0.92	1	0.156	1.00	0.1490831
Segment 3 2022 - improvement 3	1.115	0.915	1.0026285	1	1.1	1	0.94	1	1	0.49	0.92	1	0.161	1.00	0.1535239
Segment 3 2023 - improvement 3	1.115	0.915	1.0026285	1	1.1	1	0.94	1	1	0.49	0.92	1	0.166	1.00	0.1582819

Fig. 5. Analyzed database.

Principal Component Analysis (PCA) was chosen for the statistical evaluation of this study due to its ability to analyze the complex interrelationships among an extensive set of variables and explain them in terms of a reduced number of principal components. This technique, grounded in linear algebra concepts such as eigenvalues and eigenvectors, allows condensing the information contained in the original variables into a more compact set of variables, minimizing information loss. This analysis is performed using the "Real Statistics" component of Excel, where the "Factor Analysis" calculation option is selected, and the variables are chosen. (see Fig. 6).

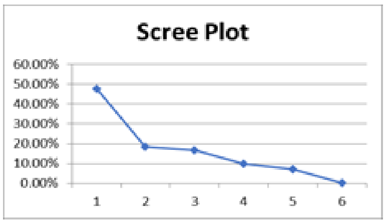


Fig. 6. Principal components

The analysis is reduced to 2 principal components, this due to the low variability of some components, such as FMC 1r, FMC 5r, FMC 6r, FMC 8r, FMC 9r, FMC 11r, FMC 12r.

TABLE XVII. EIGENVALUES OF THE PRINCIPAL COMPONENTS

eValue	%	Cum %
2.864484158	47.74%	47.74%
1.101248512	18.35%	66.10%
1	16.67%	82.76%
0.593691631	9.89%	92.66%
0.424619288	7.08%	99.73%
0.015956414	0.27%	100.00%

Next, the major variances of each principal component are identified, this is done to identify which variables compose each of them.

TABLE XVIII. VARIANCES OF THE PRINCIPAL COMPONENTS

	1	2
Berm width and type	-0.768818007	-0.157272114
Horizontal curves: Length, radius	0.078430009	-0.939823781
Horizontal curves: Superelevation	-0.676142533	0.405793424
Centerline rumble strips	0.95387289	0.113971603
Hazard index	0.948793733	0.124849608
NFDS	0	0
	2.864484158	1.101248512

After identifying the variables corresponding to each principal component, a summary table of these is prepared.

TABLE XIX. COMPOSITION OF THE PRINCIPAL COMPONENTS

Component 1	Centerline rumble strips	47.74%
	Hazard index	
Component 2	Horizontal curves: Length, radius	18.35%

A bar chart is then created to better visualize the composition of the principal components. (see Fig. 7).

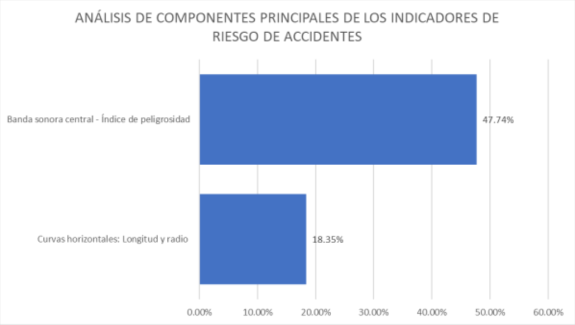


Fig. 7. Principal components

Therefore, 47.74% of the indicators are explained by the variables of Centerline rumble strips and Hazard index. Meanwhile, 18.35% of the next indicators are explained by the variables corresponding to Horizontal curves.

CONCLUSIONS

In the context of road safety, the implementation of innovative approaches has proven essential in achieving a substantial reduction in accidents. The utilization of both real and hypothetical data when implementing certain safety improvement mechanisms, through the calculation of predicted accident probabilities, was crucial for conducting this research. The importance of having an extensive database to determine the variables more accurately with the greatest impact on this calculation is emphasized. This study succeeded in identifying that, among the 14 variables composing the mentioned equation, 3 are considered of greater relevance in this calculation. The presence of centerline rumble strips and the Hazard index in the segment determined by the presence of obstacles and barriers holds an importance of 47.74%. On the other hand, variables related to horizontal curves, such as length and radius, possess an importance of 18.35%. In summary, it is concluded that this calculation could achieve greater accuracy when supplemented with data from other roads sharing similar characteristics. This would allow for the expansion of the database and confirm that the variables identified in this research should be considered a priority for all types of Second-Class Rural Roads.

REFERENCES

[1] Alghafli, A., Mohamad, E., & Ahmed, A. Z. (2021). The effect of geometric road conditions on safety performance of abu dhabi road intersections. Safety, 7(4). https://doi.org/10.3390/safety7040073

[2] Moomen, M., Rezapour, M., Raja, M. N., & Ksaibati, K. (2020). Predicting injury severity and crash frequency: Insights into the impacts of geometric variables on downgrade crashes in Wyoming. Journal of Traffic and Transportation Engineering (English Edition), 7(3), 375–383. https://doi.org/10.1016/j.jtte.2019.04.002

[3] Zhang, X., Xu, J., Liang, Q., & Ma, F. (2020). Modeling impacts of speed reduction on traffic efficiency on expressway uphill sections. Sustainability(Switzerland),12(2). https://doi.org/10.3390/su12020587

[4] Zhao, J., Guo, Y., & Liu, P. (2021). Safety impacts of geometric design on freeway segments with closely spaced entrance and exit ramps. Accident Analysis and Prevention, 163. https://doi.org/10.1016/j.aap.2021.106461

[5] Intini, P., Berloco, N., Ranieri, V., & Colonna, P. (2020). Geometric and operational features of horizontal curves with specific regard to skidding proneness. Infrastructures, 5(1). https://doi.org/10.3390/infrastructures5010003

[6] Moradi, M., Abdi Kordani, A., & Zarei, M. (2021). New Geometric Design Approach to Reduce Vehicle’s Speed in Accident-Prone Downgrade Highways Using Dynamic Vehicle Modeling. Journal of Transportation Engineering, Part A: Systems, 147(1). https://doi.org/10.1061/jtepbs.0000476

[7] Mehrara Molan, A., & Ksaibati, K. (2021). Impact of side traffic barrier features on the severity of run-off-road crashes involving horizontal curves on non-interstate roads. International Journal of Transportation Science and Technology, 10(3), 245–253. https://doi.org/10.1016/j.ijtst.2020.07.006

[8] Ciampa, D., & Olita, S. (2022). Mountain Roads’ Geometric Design: Methodological Proposal for Hairpin Bend Design/Retrofitting. Infrastructures, 7(9). https://doi.org/10.3390/infrastructures7090112

[9] Llopis-Castelló, D., Findley, D. J., & García, A. (2021). Comparison of the highway safety manual predictive method with safety performance functions based on geometric design consistency. Journal of Transportation Safety and Security, 13(12), 1365–1386. https://doi.org/10.1080/19439962.2020.1738612

[10] Wang, F., Chen, Y., Wijnands, J. S., & Guo, J. (2020). Modeling and interpreting road geometry from a driver’s perspective using variational autoencoders. Computer-Aided Civil and Infrastructure Engineering, 35(10), 1148–1159. https://doi.org/10.1111/mice.12594

[11] Zhu, B., Hou, F., Feng, T., Li, T., & Song, C. (2023). An information model for highway operational risk management based on the IFC-Brick schema. International Journal of Transportation Science and Technology. https://doi.org/10.1016/j.ijtst.2022.12.004

[12] Burghardt, T. E., Popp, R., Helmreich, B., Reiter, T., Böhm, G., Pitterle, G., & Artmann, M. (2021). Visibility of various road markings for machine vision. Case Studies in Construction Materials, 15. https://doi.org/10.1016/j.cscm.2021.e00579

[13] Hu, J., Sun, S., & Wang, R. (2022a). Research on the influence of light source characteristics on traffic visual distance in foggy areas at night. Building and Environment, 212. https://doi.org/10.1016/j.buildenv.2022.108818

[14] Yuan, M., Mai, J., Liu, X., Shen, H., & Wang, J. (2023). Current Implementation and Development Countermeasures of Green Energy in China’s Highway Transportation. Sustainability (Switzerland), 15(4). https://doi.org/10.3390/su15043024

[15] Zima, K., & Ciepłucha, W. (2023). Efficiency Analysis of Roadway Lighting Replacement in a Selected Polish Municipality. Applied Sciences (Switzerland), 13(5). https://doi.org/10.3390/app13053257

[16] Estrada, L. M., & Soto, S. P. (2021). Análisis de la seguridad vial en la Av. Atahualpa, que une los distritos de Cajamarca y Baños del Inca, aplicando la metodología de inspección de seguridad vial y el método predictivo del manual HSM 2010, para la reducción de accidentes de tránsito en el año 2021 [Tesis de licenciatura, Universidad Privada del Norte]. Repositorio de la Universidad Privada del Norte. https://hdl.handle.net/11537/28235

[17] P. J. M. Guevara Delgado and J. D. Norabuena Ita, “Análisis y Propuesta de Mejora de la Seguridad Vial en la Carretera Panamericana Norte, tramo Variante de Pasamayo del km 55 al km 70 aplicando la Metodología del Manual de Seguridad vial,” Universidad Peruana de Ciencias Aplicadas(UPC), Lima, Perú,2019. http://hdl.handle.net/10757/626485