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Proposal of New Star Rating Bands for iRAP on Two-lane Rural Roads in Ecuador

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Abstract **-** The iRAP model aims to reduce the number of road accidents or their severity by assigning a Star Rating (SR) to every 100 m of the road. The SR were derived from accident statistics and studies from several countries and organizations. However, these results may not be applicable to other countries or regions due to differences in the safety of vehicles and the behaviour of road users. This research proposes new iRAP Star Rating (SR) bands for two-lane rural roads in Ecuador. The study analysed more than 600 kilometres on the country's road network and estimated the SRS values every 100 m after collecting the road infrastructure attributes that could impact the likelihood of severity of a crash. The iRAP results were compared with the actual traffic accidents in the country, and, after statistical analysis, the study proposed new thresholds that better fit the Ecuadorian data. This process can be used by other countries to calibrate their own thresholds.

Keywords**:** Road Safety, Traffic Accidents, Two-lane rural roads, iRAP, Developing Countries

1. Introduction

The United Nations General Assembly aims to reduce road traffic deaths and injuries by at least 50 percent from 2021 to 2030 [1]. This ambitious target could be achieved through the use of complex models, such as the International Road Assessment Programme (iRAP) [2]. iRAP aims to reduce road crashes due to both social and economic issues [3], and seeks to address the approximately 1.3 million deaths caused by road accidents [4]. iRAP methodology is based on the Road Assessment Programmes (RAP) in high-income countries (EuroRAP, AusRAP, usRAP, and KiwiRAP) and expert organizations such as Australia, United Kingdom, United States, and Malaysia [3]. The iRAP procedure includes a calibration process to consider local conditions, but requires detailed crash data and research, such as Safety performance functions (SPF) to estimate the exposure i.e. Ambros and collaborators [5] . But this data is often lacking in low- or middle-income countries. When this is the case, iRAP suggests using a calibration factor of 1.

This global concern over traffic accidents has led to the expansion of iRAP to several countries or regions, including Europe, Australia, the United States of America, New Zealand, China, India, Brazil, South Africa, Thailand, Malaysia, and Pakistan [6]. Special emphasis has been placed on the factors contributing to the frequency and severity of road accidents in countries such as the United Kingdom [7], Australia [8], China [9], Canada [10], Bangladesh [11], Moldavia [12]. This ongoing research, as well as previous studies, allows iRAP to continuously improve its estimates. However, iRAP results may not be applicable to other countries or regions due to differences in the safety of vehicles or the behaviour of road users from the sites where they were modelled or calibrated.

iRAP has developed four protocols to assess and improve the safety of roads [3]. One of these protocols is the Star Rating (SR), which involves an assessment of road infrastructure attributes that could affect the likelihood and severity of crashes. Roads sections are given a rating of 1 to 5 stars based on the iRAP model's results, with the safest roads (4- and 5-star) having attributes that allow high speeds under prevailing traffic conditions, such as median for separation of opposing traffic, pedestrians footpaths, bicycle lanes, or protected areas. In contrast, the most unsafe roads (1- and 2-star) lack attributes that ensure safe circulation, such as narrow lanes, steep embankments close to the side of the road, and a lack of bicycle lanes or footpaths. To assign the SRs, it is necessary to calculate the Star Rating Scores (SRS) in the iRAP model.

The Safety Rating Score (SRS) is calculated for four groups of road users: vehicle occupants, motorcyclists, bicyclists, and pedestrians. The score reflects the relative risk of death or serious injury, considering the likelihood and severity of the road attributes, operating speed, flow, and median traversability. The Safety Rating (SR) is obtained from the SRS results using Table 1. The bands for the SR were determined based on five interrelated factors: a) the role of speed in the safe system context, b) expected injury severity, c) the use of SR in setting targets, d) the correlation between SR and crash rates, and, e) the distribution of SR across the road network [3]. These bands have been established for countries with extensive research in the field. Despite its extensive use, there have still been critiques of Star Rating procedure mainly based on the relationship between Star ratings and crashes [5] and replicate iRAP results in value of statistical life [13].

Table 1: Star Rating band (SR) for iRAP procedure [3].

Star Rating (SR)*	Star Rating Score (SRS)				
	Vehicle occupants and motorcyclists	Bicyclists		Pedestrians	
			Total	Along	Total
5	0 to < 2.5	0 to < 5	0 to < 5	0 to < 0.2	0 to < 4.8
4	2.5 to < 5.0	5 to < 10	5 to < 15	0.2 to < 1.0	4.8 to < 14.0
3	5.0 to < 12.5	10 to < 30	15 to < 40	1.0 to < 7.5	14.0 to < 32.5
2	12.5 to < 22.5	30 to < 60	40 to < 90	7.5 to < 15.0	32.5 to < 75
1	≥ 22.5	≥ 60	≥ 90	≥ 15.0	≥ 75
* 5-star are the safest road and 1-star are the most unsafe road.					

In Ecuador, few evaluations using the iRAP model have been conducted, all of which were on two-lane rural roads. For instance, the national government evaluated 520 km of the El Carmen-Manta and Riobamba-Azogues road [14]. The other studies conducted by the academia will be analysed in this study. Two-lane rural roads have one lane in each direction with a centreline and are the most common road type in most countries. The Ministry of Transport and Public Works (MTOP) in Ecuador recently presented the National Strategy for Safe Mobility 2021-2030 called ES-SEGURA [14], which mentions the use of the iRAP method. This initiative aims to design new roads with at least three stars and improve existing roads to reach that standard. In conclusion, the iRAP methodology had limited experience in the Ecuador. To ensure its suitability for local conditions, the SR ranges need to be calibrated using accident statistics and studies from several countries and organizations outside of Ecuador.

This research aims to propose new iRAP Star Rating (SR) thresholds for two-lane rural roads in Ecuador. To do so, 630 kilometres of the country's road network were analysed. These results may not be directly applicable to other countries or regions, but their methodology can be adapted to local data. The novelty contribution of this study is to highlight the need for separate value bands for each road type, as two-lane rural roads do not perform similarly to highways. It also emphasizes the need for separate bands for vehicle occupants and motorcyclists, and to use available local data to perform the analysis. The paper is organized as follows: first, the materials and methods, including the selection of roads, traffic accident data, data collection and processing, and calculation of SR bands, are presented. Next, the results and the evaluation of each road user are presented. Finally, the discussion and conclusions of the investigation are presented.

2. Materials and Methods

2.1. Selection of Road Sections

The road sections analysed had the following criteria: a) being two-lane roads, b) having a length of over 10 km, c) being rural roads, d) being in a mountainous environment, and e) having ease of access for collecting satellite or field data. Based on these criteria, 25 road sections were analysed by undergraduate and graduate students at Universidad Técnica Particular de Loja. The details of this database are shown in Table 2. The roads are located in the vicinity of the Andes mountains and a total of 630 km of two-lane roads were analysed. Further information can be found in Road Safety Observatory dashboard [15].

Table 2: Selected two-lane rural roads from Ecuador in this study.

N°	Origen-destination of the selected road	Length (km)	Source
1	Catamayo - San Pedro*	12.2	Villamagua [16]
2	Chambo – Cubijíes	20	Salazar [17]
3	Cuchaentza – Macuma	20	Cabrera [18]

4	Cuenca - Girón	20.1	Azanza [19]
5	Cuenca - Loja	20.1	Muñoz [20]
6	Cuenca - Molleturo	20	Abril [21]
7	Molleturo - El Empalme	20.1	Guerrero [22]
8	El Descanso - Malima	28.8	Suárez [23]
9	Gualaceo - Limón Indanza	20.3	Cuadrado [24]
10	La Era - Indiucho	20.8	Muñoz [25]
11	Las Chinchas - Zambi	20	Loyola [26]
12	Loja – Catamayo*	31.6	Villamagua [16]
13	Loja - Jimbilla	20.1	Arteaga [27]
14	Loja - Saraguro	64.3	Vega [28]
15	Loja - Yangana	55.8	Camacho [29]
16	Loja - Zamora	57.7	Montoya [30]
17	Malacatos - La Era	20	Puchaicela [31]
18	Puyo - Nuevos Horizontes	23.2	Escobar [32]
19	Riobamba - Penipe	20	Guacho [33]
20	San Pedro - Las Chinchas*	11.9	Villamagua [16]
21	Sunamanga - Sacapalca	18.9	Requelme [34]
22	Tabacay - Cochahuayco	23.7	González [35]
23	Villonaco - Chuquiribamba	20	Caraguay [36]
24	Yangana - Sabanilla	20.1	Pardo [37]
25	Ye de Olmedo - Chaguarpamba	20	Coronel [38]

* This roads belong to the same study.

2.2. Crash Data

To compare the results of iRAP procedure's SRS and SR values, traffic accidents that occurred on the roads listed in Table 2 were collected. The data included all available information on fatal, injured and property damage only. The Agencia Nacional de Tránsito provides that information at https://www.ant.gob.ec/visor-de-siniestralidad-estadisticas/ [39]. The database available on this website has data from the year 2017. This study analyzed data from 2017 to 2021 (as summarized in Table 3). As the data are georeferenced, each road accident was associated with a specific 100-m road section. The low number of accidents involving cyclists is due to the limited flow of cyclist on two-lane roads lanes, particularly in rural areas.

Table 2: Summary of the accident data recorded on the roads in Table 2.

Year*	Vehicle Occupants related	Motorcyclists related	Bicyclists related	Pedestrians related
2017	50	76	0	7
2018	64	76	0	12
2019	61	62	1	12
2020	48	59	0	9
2021	64	71	0	12
Total	287	344	1	52

* The 2017 is the first year available in the Agencia Nacional de Tránsito from Ecuador.

2.3. Road Attributes Collection

Several information sources provided the road attributes used in the iRAP procedure. Road geometry designs were collected using as-built plans, and when this information was unobtainable, it was estimated using satellite images. Data on road operation, such as the pedestrian flows, was obtained through previous studies or in-situ counting. The operating speeds were calculated using the local equations from a similar road study [40]. Some data, such as lane width was measured in situ on each road. The remaining road attributes were measured indirectly using georeferenced videos obtained from smartphones GPS. The videos captured images of the road sections every 100 m, showing roadside elements like a tree or a pole. These images were used to measure some characteristics such as the tree's diameter or distance from the road by scaling the image to known information, such as the lane width.

2.4. Road Attributes Data Processing

Each measured road attribute was assigned a code according to the iRAP procedure. For example, a lane width of 3.00 m was classified as medium category (between >= 2.75m and < 3.25m). This code is associated with specific risk factors for each road user and crash type. This coding was done for every 100 m road section, with a total of around 6300 sections and over 50 attributes analyzed for each section.

2.5. Star Rating bands estimation

The coded attributes were uploaded to the ViDA software available at https://vida.irap.org/en-us/home [41]. This study utilized the demonstrator option of the online software, which is freely available from iRAP. The Star Rating Score (SRS) for vehicle occupants, motorcyclists, bicyclists, and pedestrians were calculated for every road section. The SRS of each section was compared to the number of road accidents registered in the five-year data. This comparison was made possible due to the geolocation information in both databases. Before performing this comparison, the database was organized into five groups based on the registered road accident data. The number of groups corresponded to the number of stars assigned by iRAP. Sites without accidents received 5 stars, while the sites with the most crashes received 1 star, and the rest received intermediate values. In this study, the relationship was: 5-stars = 0 accidents, 4-stars = 1 accident, 3-stars = 2 accidents, 2-stars = 3 accidents, and 1-star > 3 accidents in all five years of analysis. Since the groups should be based on the accident data of all four users, the decision was made to use the traffic accident statistics of the vehicle occupants, as their frequency or severity affects the other users. Other methods such as empirical Bayes approach [5].

The SRS values were analyzed in each constructed group using a preliminary boxplot analysis to understand the trends in each group. The descriptive statistics of the SRS, including the average, standard deviation, confidence intervals, median, and quartiles of the median (Q1 and Q3) were calculated for each group. However, due to inconsistent results from the average and standard deviation, only the median and quartiles were used to determine the new SR bands. The 1st and 3rd quartiles ensure data between 25% to 75% and exclude high or low values. All this analysis was performing using Minitab statistical software [42], and the new SR bands were assigned based on these descriptors to ensure consistency between the different groups.

3. Results

3.1. Preliminary analysis

After assigning each SRS value to a group based on its accident rate, a boxplot was made to examine the trends in the data, as shown in Fig. 1. In this figure, there are many sites without registered traffic accidents, compared to the other groups. The logical trend would be for group 5 to have lower values than the other the groups, but this is not reflected in the figure. In addition, for all users, this group has a higher dispersion than the rest. Group 2 also does not follow the expected trend, as it has high median values and high scatter, even higher than group 1, which should have the highest values. In contrast, groups 1, 3, and 4 follow the consistent trend with the iRAP procedure, which states that higher SRS values indicate greater danger and vice versa.

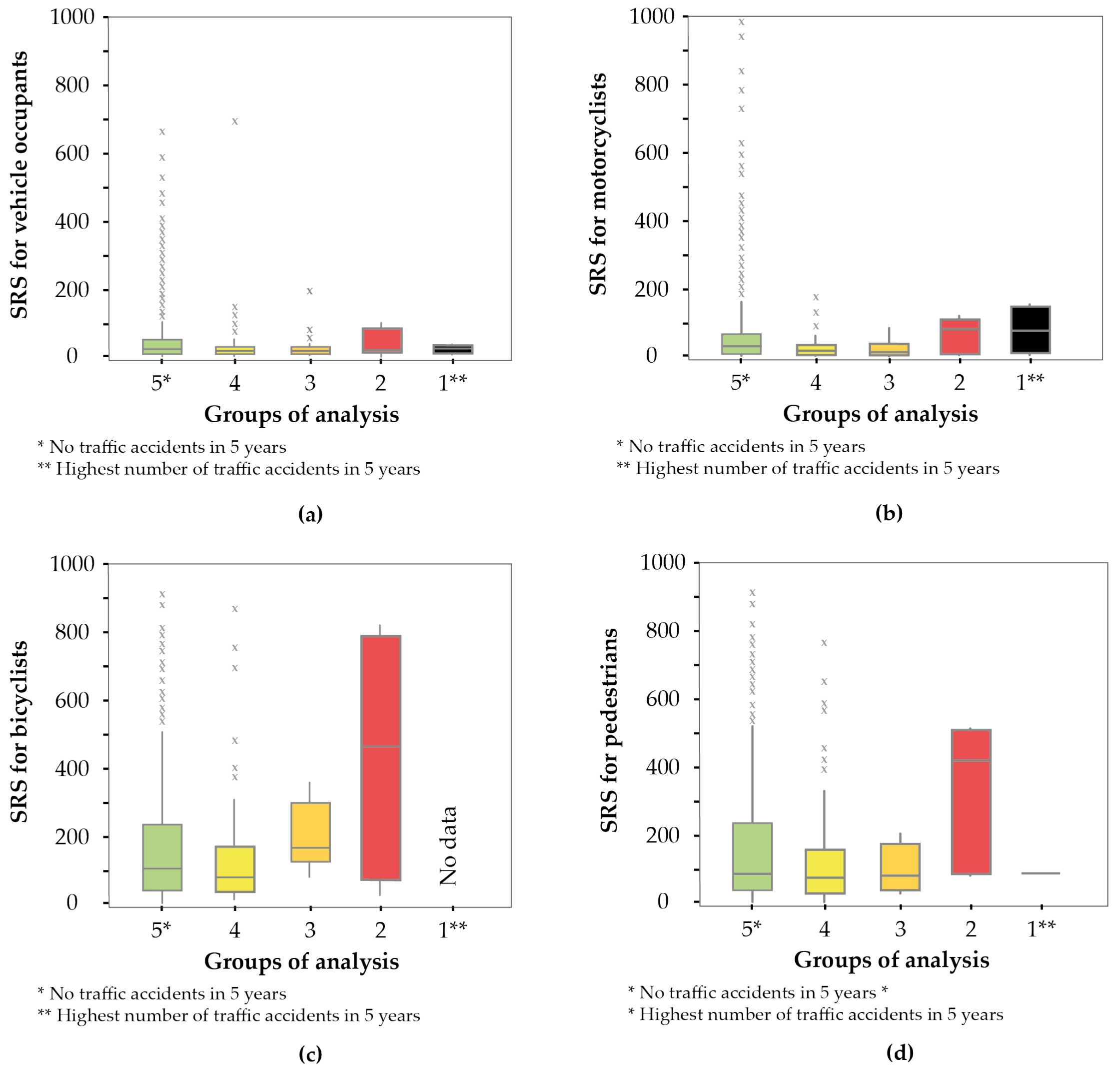

Fig. 1: Boxplot of the five groups from lowest to highest accident rate with respect to the Star Rating Score (SRS) calculated on the roads under study: (a) SRS boxplot of vehicle occupants based on accident rate; (b) SRS boxplot of motorcyclists based on accident rate; (c) SRS boxplot of bicyclists based on accident rate; (d) SRS boxplot of pedestrian based on accident rate

3.2. Vehicle occupants

Table 4 displays the descriptive statistics of SRS values assigned to each group of road sections based on their registered accident rate for vehicle occupants. The data shows that the number of road sections without any accidents is the highest, confirming their status as the safest group. The table demonstrates the median and quartile values for each group, providing a comprehensive understanding of the distribution of the SRS values. Table 4 also shows the proposed bands. These proposed Star Rating bands were obtained from the descriptive statistics of groups 1, 3, and 4, which showed a consistent trend with iRAP procedure. The rest of the groups' thresholds (2 and 5) were completed with the bands obtained from the other groups.

The process of assigning the bands was as follows. The bands for groups 4, and 5 and the lower value of group 3 were determined from the Q1 and Q3 of group 4. Q3 of group 3 was used as the upper value of group 3 and the lower value of group 2. Finally, Q3 of group 1 was used to determine the upper value of group 2 and the main threshold for group 1.

Table 4. Descriptive statistics of vehicle occupants and proposed Star Rating band.

N° of traffic accidents in five years	Group or Star Rating	N	Median	Q1	Q3	Proposed Star Rating band
0	5[1]	4913	26.99	26.24	27.58	0 to < 18
1	4	216	20.20	**18.28**	**22.38**	18 to < 22
2	3	23	20.62	15.20	**27.18**	22 to < 27
3	2	7	24.70	15.59	90.89	27 to < 37
>3	1[2]	4	27.36	16.91	**36.58**	≥ 37

[1]No traffic accidents in 5 years, [2]Highest number of traffic accidents in 5 years. Note that the values in bold were the used to set the new bands.

3.3. Motorcyclists

Table 5 shows the descriptive statistics of the motorcyclists. This is similar to that of vehicle occupants, as seen in the table. The band selection process was the same as vehicle occupants, but since there were no records in group 1, the median of group 2 was used as the upper threshold for group 4 and the upper band for group 1. It is worth noting that the thresholds between vehicle occupants and motorcyclists are different (compare Tables 4 and 5), which differs from the iRAP bands, considering them as equal.

Table 5. Descriptive statistics of motorcyclist and proposed Star Rating band.

N° of traffic accidents in five years	Group or Star Rating	N	Median	Q1	Q3	Proposed Star Rating band
0	5[1]	2069	31.38	30.39	33.67	0 to < 22
1	4	96	25.76	**21.68**	**30.46**	22 to < 30
2	3	9	22.64	15.90	**57.76**	30 to < 58
3	2	5	**90.48**	6.44	126.62	58 to < 90
>3	1[2]	0	-	-	-	≥ 90

[1]No traffic accidents in 5 years, [2]Highest number of traffic accidents in 5 years. Note that the values in bold were the used to set the new bands.

3.4. Bicyclists

Table 6 displays the descriptive statistics of the cyclists. The trend shown in the table is similar to that of the previous two groups. The band selection process was the same as for motorcyclists where no data was available for group 1.

Table 6. Descriptive statistics of bicyclist and proposed Star Rating band.

N° of traffic accidents in five years	Group or Star Rating	N	Median	Q1	Q3	Proposed Star Rating band
0	5[1]	1553	112.54	95.6	119.66	0 to < 71
1	4	82	83.61	**70.91**	**119.31**	71 to < 119
2	3	7	175.58	119.69	**320.20**	119 to < 320
3	2	4	**467.17**	31.82	822.05	320 to < 467
>3	1[2]	0	-	-	-	≥ 467

[1]No traffic accidents in 5 years, [2]Highest number of traffic accidents in 5 years. Note that the values in bold were the used to set the new bands.

3.5. Pedestrians

Table 7 shows the descriptive statistics of pedestrians. The band selection was the same as for motorcyclists and cyclists. The proposed bands are for overall number of pedestrians. The iRAP procedure has three bands for pedestrians: total, along, and crossing, but it was not possible to calculate these bands due to the lack of detailed statistics in the ANT.

Table 7. Descriptive statistics of bicyclist and proposed Star Rating band.

N° of traffic accidents in five years	Group or Star Rating	N	Median	Q1	Q3	Proposed Star Rating band
0	51	1638	95.73	95.72	99.58	0 to < 65
1	4	87	80.78	**64.62**	**96.89**	65 to < 97
2	3	8	90.19	43.89	**190.05**	97 to < 190
3	2	3	**428**.11	95.73	513.73	190 to < 428
>3	12	0	-	-	-	≥ 428

[1]No traffic accidents in 5 years, [2]Highest number of traffic accidents in 5 years. Note that the values in bold were the used to set the new bands.

3.6. Comparison of the new bands with the original iRAP values

Fig. 2 illustrates the difference between current values and the proposed ones by showing the increased factors between them. For example, the original upper threshold for 5-stars for pedestrians is 5, while the proposed one was 65, which represents an increase of 13. These values and other factors were plotted in Fig. 2. The highest increase was observed for cyclists, followed by pedestrians and motorcyclists. Despite the significant increase in the 5-stars threshold, all thresholds have been raised to accommodate the statistics collected on the two-lane roads analysed.

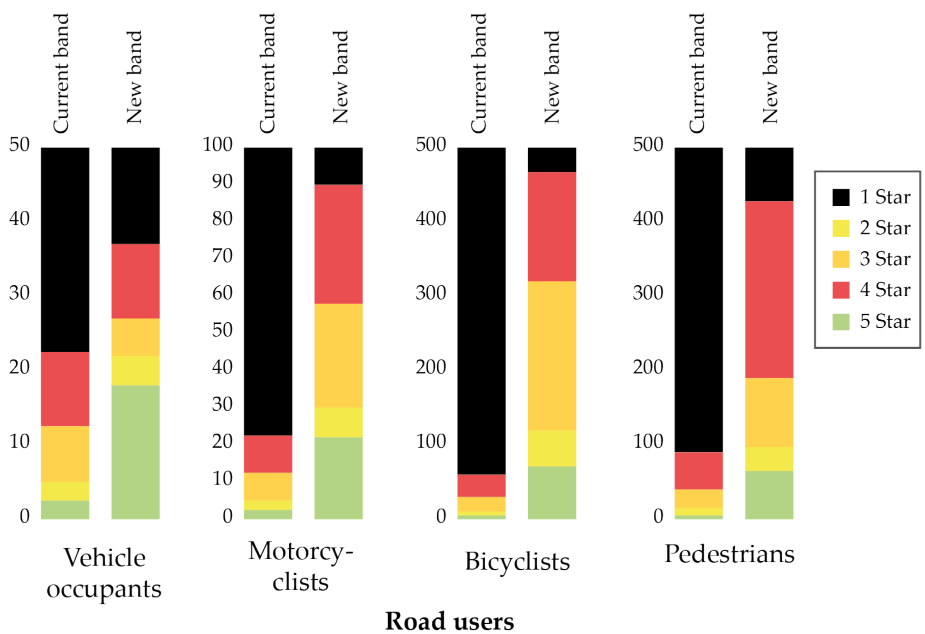

Fig. 2: Incremental factors between original and proposed SRS bands.

4. Discussion

The proposed bands are more suitable for the data collected on two-lane rural roads. It is logical that sites with no traffic crashes do not require any road safety intervention. In countries with budget constraints, such as Ecuador, the high cost of the current bands of iRAP method may discourage its use. And on the other hand, locally adjusted values may promote its expansion. This study proposes different thresholds for the vehicle and motorcycle occupants, who are using a motor vehicles, but motorcyclists have a higher risk due to their lower protection. These new bands can be analyzed in future versions of iRAP. The SRS is used to analyze the situations before or after a countermeasure. The number of fatalities and serious injuries before and after the intervention, as well as the SRS before and after, are recorded If the SRS is not adjusted to local data, it may result in an increase or decrease fatalities or serious injuries, compromising the project from both an economic and technical perspective. The difference between the international SRS bands and those calibrated in this study is mainly due the fact that rural roads have few users of motorcyclists, pedestrians, and cyclist who are the most vulnerable road users.

The study supports the use of iRAP but highlights the importance of calibrating its bands to local data for better results. The study does not suggest modifying iRAP method, but rather encourages the analysis of the procedure before applying it. Other road safety assessment tools are available, but iRAP stands out for its versatility and contribution to research in road safety. It can be applied in various scenarios, including road design near schools. The study provides a valuable addition to the existing knowledge on iRAP.

The readers may consider the proposed method for new bands, which only includes the severity and not the likelihood of the crash risk. In Ecuador, there is limited traffic crash data available, so all the data including fatal, injury and property damage only crashes were used. These crashes are a result of traffic risk variables such as likelihood, severity or both. In iRAP, some road attributes contribute to both likelihood and severity. A rational question arises, why did the study not focus on calibrating the risk factor of the road attributes instead of SR bands? The answer is that we did not have all the detailed information needed to calibrate all the risk factors. This limited information may be similar in other countries, so the presented procedure could help other nations propose their bands.

5. Conclusions

The aim of the study was to propose new iRAP Star Rating (SR) bands for two-lane rural roads in Ecuador. To achieve this goal, data was collected from almost 630 km of two-lane roads in mountainous environments. The following conclusions were reached. Different thresholds for the five stars of the iRAP procedure were proposed based on the data recorded over five years. Separate bands for motorcyclists and vehicle occupants were estimated, which were equal to the iRAP procedure and more adjusted to the local conditions of two-lane rural roads. These bands allow sites with low probability of accidents in local environments without incurring additional expenses and align with the tight budget usually found in Latin American countries. However, his article has limitations. Only few sections of the country's two-lane roads network were analysed, but data collection consumes significant resources. It is necessary to mention those roads were placed in mountainous environments and did not include another type of roads. Traffic data from 5 previous years were used which are those available on the Government website. Despite these limitations, the study presents a methodology for modifying the SR bands in the iRAP and highlights the need for future research on different type of roads and among vehicle occupants and motorcyclists, using local data. The validity of the new bands should be studied in the future. It can be done on other two-lane roads or with traffic accident records to be recorded from now on, or even in other countries.

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