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Original Article

Analysis of the Effect of Road Geometric Factors on Accident Frequency and Safety Level on the Sungai Duren-Sungai Buluh Road Section in Jambi Province

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Abstract

Road infrastructure conditions, particularly geometric characteristics, are important factors that may influence traffic accident risk on provincial road sections. This study examines the effect of road geometric factors on traffic accident frequency and evaluates the road safety level of the Sungai Duren-Sungai Buluh Road section in Jambi Province, Indonesia. A quantitative explanatory design was applied to a 13 km road section divided into 130 segments of 100 m. Accident data were obtained from the Integrated Road Safety Management System of the Jambi Regional Police for the 2019-August 2025 period, while geometric and road safety attribute data were collected from as-built drawings, field surveys, and video-based road inventory. Poisson regression was used to identify factors affecting accident frequency, and the iRAP Star Rating method was applied to assess infrastructure-related safety risk. The results show that hilliness, bendiness, and operating speed have significant positive effects on accident frequency, with significance values of 0.007, 0.042, and 0.038, respectively. Segments without berms were more vulnerable to accident risk, particularly due to hilliness, operating speed, and pavement condition. The iRAP assessment showed that 84.6% of the segments were classified as 1-star and 2-star roads, indicating a low safety level. The improvement simulation increased the Star Rating from 1 Star to 4 Stars through targeted infrastructure interventions. These findings imply that integrating Poisson regression and iRAP assessment can support data-driven prioritization of road safety improvements on high-risk provincial road segments.

Keywords: Accident Modelling, iRAP, Poisson Regression, Road Infrastructure, Safety.

1. Introduction

Traffic accidents remain a major challenge in road transportation systems because they cause fatalities, property damage, and safety risks for road users. These accidents are influenced not only by human and vehicle-related factors, but also by road infrastructure conditions, particularly road geometric characteristics. Factors such as hilliness, bendiness, road width, shoulder condition, and operating speed may affect vehicle stability, sight distance, and drivers' ability to maintain control. On road sections with curves, downgrades, and heavy vehicle traffic, accident risk may increase when geometric conditions are not supported by adequate safety facilities (Donnell et al., 2019).

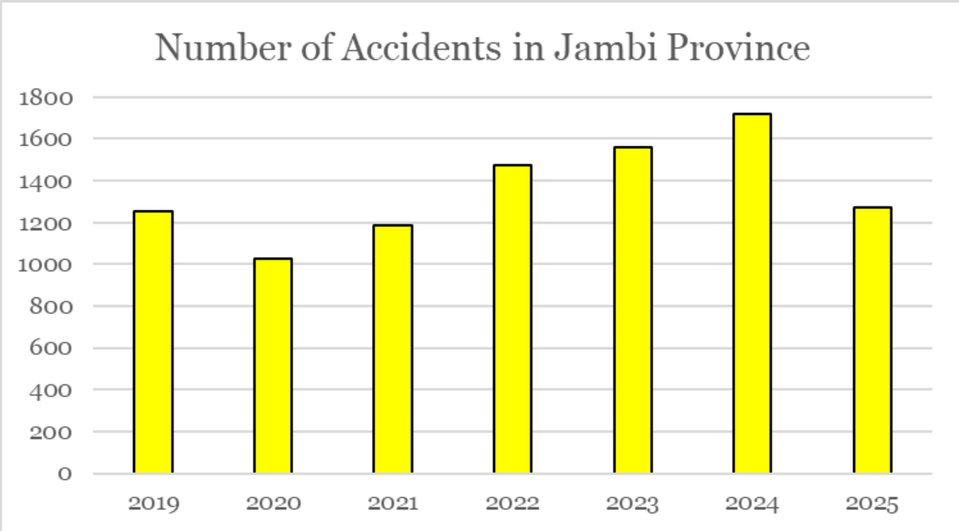


Figure 1. Number of Accidents in Jambi Province from 2019 to August 2025

As shown in Figure 1, traffic accidents in Jambi Province fluctuated during 2019-2025, but generally increased after 2021 and reached their highest level in 2024. Although the 2025 data only cover the period up to August, the number of recorded accidents remains relatively high. This indicates that road safety in Jambi Province remains a critical issue, particularly on road sections with high-risk geometric and operational characteristics. One important section to examine is the Sungai Duren-Sungai Buluh Road section, which serves both light and heavy vehicles. This road section is characterized by curves, downgrades, road narrowing, elevation variation, and varying shoulder and pavement conditions, which may contribute to accident risk. Previous studies have also shown that road geometry, vehicle speed, and traffic characteristics are associated with accident frequency and severity (Leni et al., 2020; Putri et al., 2025).

Although road geometric factors have been widely studied, research integrating statistical accident analysis with iRAP-based road safety assessment on non-toll provincial roads remains limited. Such integration is important because it identifies significant accident-related factors while also evaluating the physical safety level of road infrastructure. Therefore, this approach can support more measurable and risk-based infrastructure improvement recommendations. This study aims to analyze the effect of road geometric factors on traffic accident frequency and assess the road safety level of the Sungai Duren-Sungai Buluh Road section in Jambi Province. Poisson regression is used to analyze accident frequency, while the iRAP Star Rating method is applied to evaluate road safety performance. The findings are expected to provide a data-driven basis for developing road infrastructure improvement recommendations according to the safety risk level of each road segment.

2. Literature Review

2.1. Road Geometric Characteristics and Traffic Accident Risk

Road geometric characteristics are key factors influencing the safety performance of a road section. In general, road geometry consists of vertical alignment, horizontal alignment, and cross-sectional elements. Vertical alignment refers to changes in road elevation, including upgrades, downgrades, and vertical curves, while horizontal alignment describes changes in road direction and curvature. Cross-sectional elements, such as lane width, shoulder width, and median, affect vehicle movement, lateral clearance, sight distance, braking demand, and driver control under different road and traffic conditions.

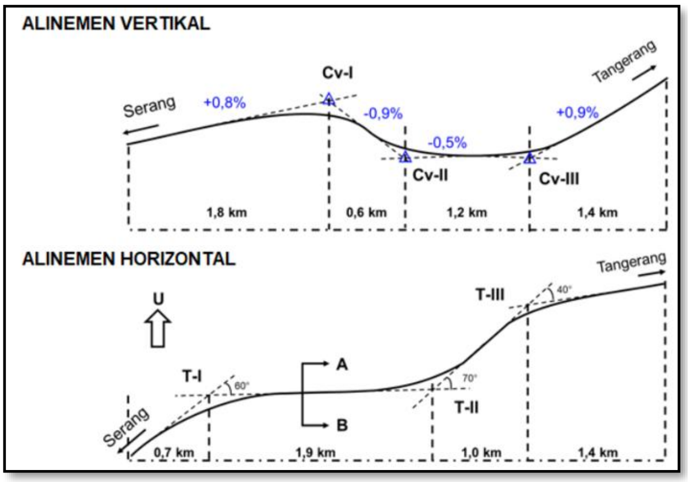


Figure 2. Illustration of Vertical and Horizontal Road Alignment

As illustrated in Figure 2, vertical alignment is closely related to hilliness, which represents elevation variation along a road section. In this study, hilliness is expressed in m/km and calculated as the total absolute elevation change divided by the total road segment length:

$$HI = \frac{\sum |\Delta h|}{L_{total}}$$

where HI is the hilliness index in m/km, $\Sigma|\Delta h|$ is the total absolute elevation change in meters, and Ltotal is the total road length in kilometers. The classification of hilliness is presented in Table 1.

Table 1. Hilliness Classification Based on Vertical Curvature

Terrain Type	Description	Vertical Curvature Rise-Fall (m/km)
F	Flat	< 10
R	Rolling	10-30
H	Hilly	> 30

Based on Table 1, a higher hilliness value indicates greater elevation variation, which may increase braking demand and reduce vehicle control, particularly on downgrades and for heavy vehicles. Horizontal alignment is associated with bendiness, which reflects the intensity of road curvature. Bendiness is expressed in degrees per kilometer (°/km) and calculated as the total absolute change in horizontal direction divided by the total road segment length:

$$BI = \frac{\sum |\Delta \theta|}{L_{total}}$$

Where BI is the bendiness index in °/km, $\sum |\Delta \theta|$is the total absolute change in horizontal deflection angle in degrees, and $L_{total}$is the total road length in kilometers. The classification of bendiness is presented in Table 2.

Table 2. Bendiness Classification Based on Horizontal Alignment

Horizontal Alignment Type	Degrees/km
Straight	0-50
Curved	50-150
Winding	150-300
Tortuous	> 300

Based on Table 2, a higher bendiness value indicates a more curved horizontal alignment and a greater potential safety risk. Road sections with 0-50 degrees/km are classified as straight, while higher values are categorized as curved, winding, or tortuous. As bendiness increases, drivers may face greater lateral forces, reduced sight distance, and more difficulty maintaining vehicle stability. These conditions may increase the likelihood of loss-of-control crashes, especially when combined with high operating speed.

In addition to hilliness and bendiness, lane width, shoulder width, and superelevation are also important geometric variables in road safety analysis. These variables were obtained from as-built drawings, which provide information on the road's longitudinal profile, horizontal alignment, cross-section, curve radius, lane width, shoulder, and superelevation. Lane width represents the available movement space for vehicles, shoulder width provides recovery space when vehicles deviate from the travel lane, and superelevation helps maintain vehicle stability on curves by reducing lateral forces.

Previous studies have shown that road geometric factors, traffic heterogeneity, and vehicle speed are associated with accident frequency and severity on inter-urban and curved road sections in Indonesia (Leni et al., 2020; Putri et al., 2025; Suraji & Mulyono, 2022). Therefore, road geometry should be considered not only as a design element, but also as a key safety factor. This is particularly relevant to the Sungai Duren-Sungai Buluh Road section, which is characterized by curves, downgrades, elevation variation, road narrowing, mixed traffic, and heavy vehicle movements. Accordingly, this study examines hilliness, bendiness, operating speed, berm availability, pavement condition, and other supporting geometric variables to explain their contribution to accident frequency and road safety performance.

2.2. Accident Frequency Modelling Using Poisson Regression

Poisson regression is a statistical method used to analyze count data, such as the number of traffic accidents observed within a specific period or road segment. In road safety studies, accident frequency is expressed as non-negative integers, making Poisson regression more suitable than ordinary linear regression because accident data are discrete and generally do not follow a normal distribution (Washington et al., 2020). The general form of the Poisson regression model is expressed as follows:

$$\ln(\lambda_i) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k$$

or can be written as:

$$\lambda_i = e^{\beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k}$$

where:

λ_i	= the expected value or average number of events in the i-th observation.
$\ln(\lambda_i)$	= the natural logarithm of the average number of events in the i-th observation.
e	= the exponential number or Euler's constant, approximately 2.718.
β_0	= the constant or intercept of the model.
$\beta_1, \beta_2, \ldots, \beta_k$	= the regression coefficients of each independent variable.
$X_1, X_2, \ldots, X_k$	= the independent variables or predictor variables used in the model.

k = the number of independent variables in the model.
i = the index of observation or the i-th observation unit.

The Poisson regression model uses a logarithmic link function to relate the expected accident frequency to the independent variables while ensuring positive predicted values. In this model, λ_i represents the expected number of accidents in segment i, β_0 is the intercept, β_1 to β_k are the regression coefficients, and X_1 to X_k represent explanatory variables such as hilliness, bendiness, operating speed, pavement condition, berm availability, and other geometric or operational attributes. Poisson regression assumes count-based dependent variables, independent observations, equidispersion, and no high multicollinearity. When the variance exceeds the mean substantially, overdispersion may occur, making the model less appropriate (Hilbe, 2014). Therefore, model suitability was evaluated using Deviance and Pearson Chi-Square values, where a value divided by degrees of freedom close to 1 indicates an acceptable model. The results were interpreted using coefficients and Exp(B), where the coefficient indicates the direction of the relationship and Exp(B) represents the accident count ratio for each one-unit increase in an independent variable.

2.3. Road Safety Assessment Using iRAP Star Rating

Road safety assessment in this study refers to the Directorate General of Bina Marga Number 11/SE/Db/2024 guideline on Roadworthiness Testing Using Star Rating (Dirjen Bina Marga, 2024). This guideline evaluates road infrastructure safety based on physical and operational attributes, which are then converted into a Star Rating. In the iRAP framework, 1 star represents the highest risk of fatal and serious injuries, while 5 stars represents the lowest risk (iRAP, 2024). The assessment was conducted by inventorying road attributes in each 100-meter segment, including traffic volume, operating speed, speed limit, road type, lane width, shoulder condition, gradient, curvature, pavement condition, delineation, lighting, roadside access, intersections, and other safety elements (Dirjen Bina Marga, 2024). In general, the Star Rating Score (SRS) is formulated as follows:

$$SRS = SRS_{Run-off} + SRS_{Ho-Loc} + SRS_{Ho-ot} + SRS_{Int} + SRS_{Pa}$$

Where:
SRS = Star Rating Score.
SRS_{Run-off} = score for crashes caused by vehicles running off the road.
SRS_{Ho-Loc} = score for head-on crashes caused by loss of control.
SRS_{Ho-ot} = score for head-on crashes caused by overtaking.
SRS_{Int} = score for crashes at intersections.
SRS_{Pa} = score for crashes at property access points.

The SRS represents the accumulated risk score of several crash components within a road segment. A higher SRS indicates a higher safety risk and therefore a lower Star Rating. Conversely, a lower SRS indicates a safer road condition and a higher Star Rating. Thus, the Star Rating system provides a practical and easily interpretable measure of road safety performance and helps identify infrastructure improvement priorities (Dirjen Bina Marga, 2024; iRAP, 2024).

Table 3. Star Rating Score Classification

Star Rating Category	Score	Color Category
5 Star	0.0 to < 2.5	Green
4 Star	2.5 to < 5.0	Yellow
3 Star	5.0 to < 12.5	Orange
2 Star	12.5 to < 22.5	Red
1 Star	≥ 22.5	Black

Based on the table 3, road segments with a 5-star rating indicate the highest level of safety because they have the lowest risk score, while road segments with a 1-star rating indicate the lowest level of safety because they have the highest risk score. Therefore, the star rating classification can be used to identify road segments that require priority treatment, particularly those categorized as 1-star and 2-star segments.

In this study, the iRAP Star Rating method complements the Poisson regression analysis. Poisson regression identifies geometric and operational factors that influence accident frequency, while the Star Rating assessment describes the physical safety level of each road segment. Combining these two approaches enables the formulation of more objective, measurable, and risk-based road infrastructure improvement recommendations.

2.4. Previous Research

Road safety research has increasingly shifted from descriptive analysis toward quantitative approaches based on crash data, road geometric characteristics, and infrastructure safety assessment. Previous studies in Indonesia have shown that geometric variables, including hilliness, bendiness, horizontal and vertical alignment, operating speed, and traffic heterogeneity, are associated with accident frequency and severity on inter-urban and curved road sections (Putri et al., 2025; Suraji & Mulyono, 2022). In addition, the iRAP Star Rating method has been widely used to evaluate infrastructure-related safety risk based on physical road attributes and to support road safety improvement planning (Dirjen Bina Marga, 2024; iRAP, 2024).

However, statistical accident modelling and iRAP-based road safety assessment are still commonly applied separately. This study integrates Poisson regression, road geometric data, and iRAP Star Rating assessment into a single road safety analysis framework. The integrated approach identifies geometric and operational factors affecting accident frequency while also linking them to the physical safety level of the same road segments. In addition, this study examines berm availability and simulates infrastructure improvement scenarios to evaluate the potential increase in Star Rating. Therefore, this study provides a practical, measurable, and evidence-based approach for prioritizing safety improvements on high-risk road sections.

3. Methods

3.1. Research Design

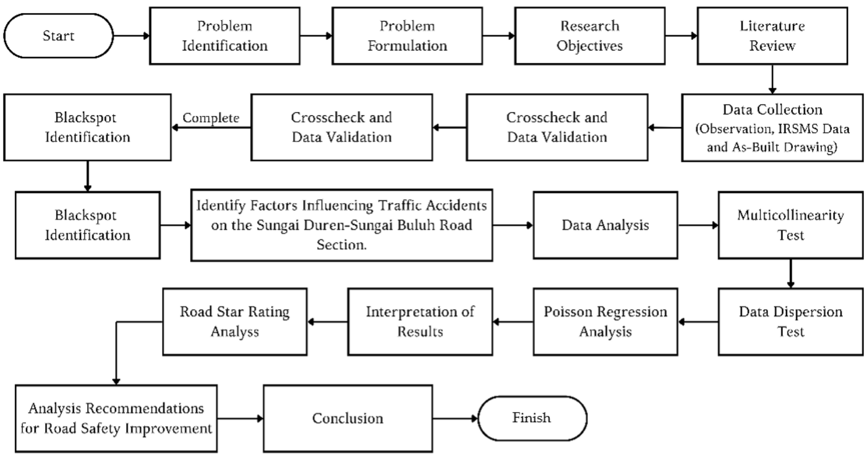


Figure 2. Research Flowchart

This study employed a quantitative explanatory design to examine the effect of road geometric factors on accident frequency and to assess road safety levels using the iRAP Star Rating method. The study was conducted on the 13 km Sungai Duren-Sungai Buluh Road section, in Jambi Province, which was divided into 130 segments of 100 m each. The data consisted of traffic accident records from the Jambi Regional Police IRSMS for the 2019-August 2025 period, road geometric data from as-built drawings, and road safety attribute data from field surveys. Accident frequency in each segment was used as the dependent variable, while the independent variables included hilliness, bendiness, operating speed, lane width, shoulder width, superelevation, pavement condition, delineation, street lighting, and berm availability. Poisson regression was applied because the dependent variable was count data, with multicollinearity and goodness-of-fit tests conducted before model estimation to ensure model feasibility and detect potential overdispersion. The iRAP Star Rating assessment was then used to evaluate the safety level of each segment based on the Directorate General of Bina Marga guideline on Roadworthiness Testing Using Star Rating. Finally, the Poisson regression and iRAP results were integrated to formulate objective, measurable, and risk-based infrastructure improvement recommendations.

3.2. Data Collection Method

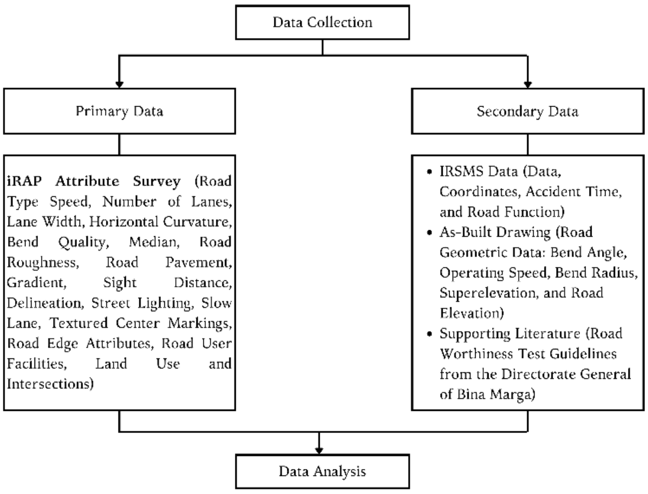


Figure 3. Data Collection Flowchart

Data collection consisted of primary and secondary data, as shown in Figure 4. Primary data were obtained through field observations and video-based road inventory to identify the road safety attributes required for the iRAP Star Rating assessment, including road type, operating speed, lane width, curvature, curve quality, pavement condition, gradient, sight distance, delineation, street lighting, road markings, roadside attributes, land use, and intersections. These attributes were coded based on the Directorate General of Bina Marga guideline on Roadworthiness Testing with Star Rating and used to calculate the safety risk score for each segment. Secondary data were obtained from official documents and technical records, including traffic accident data from the Jambi Regional Police IRSMS for the 2019-August 2025 period and road geometric data from as-built drawings, such as bend angle, operating speed, curve radius, superelevation, and road elevation. Supporting literature and the Star Rating guideline were also used as references for the iRAP-based safety assessment.

Table 4. Research Variable Data for Poisson Regression Model

Type of Variable	Variable Name	Symbol	Unit	Data Source
Dependent	Number of Traffic Accidents	Y	cases/ segment	IRSMS Jambi Regional Police
Independent	Hilliness	X1	m/km	As-built drawing
Independent	Bendiness	X2	°/km	As-built drawing
Independent	Lane Width	X3	m	As-built drawing
Independent	Road Shoulder Width	X4	m	As-built drawing
Independent	Superelevation	X5	%	As-built drawing
Control	Operating Speed	X6	km/h	As-built drawing
Control	Presence of Median	X7	0/1	Observation
Control	Pavement Condition	X8	0/1	Observation
Control	Delineation	X9	0/1	Observation
Control	Street Lighting	X10	0/1	Observation

Based on Table 4, the variables in this study consisted of dependent, independent, and control variables. All data were compiled into a segment-based dataset for Poisson regression analysis and iRAP Star Rating assessment.

3.3. Population and Research Sample

The population of this study consisted of all road segments along the Sungai Duren-Sungai Buluh Road section, in Jambi Province. In the initial stage, the road section was divided into 1-km segments to identify accident-prone locations using IRSMS accident data for the 2019-August 2025 period. The research sample was selected through risk-based purposive sampling based on Equivalent Accident Number (EAN) and Average Crash Frequency (ACF) analyses. EAN was used to account for accident severity, while ACF was used to measure accident frequency in each segment. The identified blackspot segments are presented in Table 5.

Table 5. Research Sample Based on Blackspot Identification

Segment	Road Section	EAN	ACF
17	KM. 17+000 - KM.18+000	Blackspot	No
18	KM. 18+000 - KM.19+000	Blackspot	Blackspot
22	KM. 22+000 - KM.23+000	Blackspot	No
26	KM. 26+000 - KM.27+000	Blackspot	Blackspot
29	KM. 29+000 - KM.30+000	Blackspot	Blackspot

Based on Table 5, the selected segments had a higher accident risk than other segments. The EAN method identified more accident-prone segments because it considers accident severity, while the ACF method supported the selection based on accident frequency. Therefore, the blackspot segments were used as the basis for determining the research sample. The KM 17+000 to KM 30+000 section was then selected for further analysis using Poisson regression and iRAP Star Rating assessment.

3.4. Data Analysis Methods

Data analysis was conducted in several stages to examine the effect of road geometric factors on accident frequency and assess road safety levels in the study area. First, accident data, road geometric data, and road safety attributes were organized into a segment-based database. Multicollinearity and goodness-of-fit tests were then performed to ensure the feasibility of the Poisson regression model. Poisson regression was applied using SPSS because the dependent variable was count data, namely accident frequency in each road segment. Next, road safety levels were assessed using the iRAP Star Rating method. Finally, the regression and iRAP results were integrated to formulate risk-based infrastructure improvement recommendations.

Table 6. Stages of Data Analysis

Stage	Analysis Method	Objective	Output
1	Segment-based database preparation	To combine accident data, road geometric data, and iRAP attributes	Dataset for each segment
2	Multicollinearity test	To ensure that there is no strong relationship among independent variables	Tolerance and VIF values
3	Dispersion and goodness-of-fit test	To determine the feasibility of using the Poisson model	Deviance,Pearson Chi-Square
4	Poisson regression using SPSS	To analyze the effect of geometric road factors on the number of accidents	Coefficient, Sig., and Exp(B)
5	iRAP Star Rating	To assess the road safety level in each segment	Star Rating value
6	Integration of analysis results	To formulate infrastructure improvement recommendations	road safety recommendations

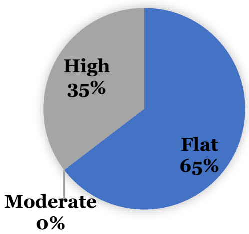
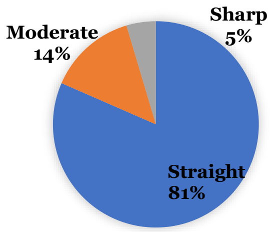
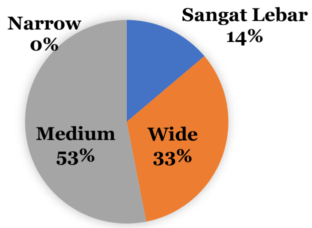
4. Results and Discussion

4.1. Research Results

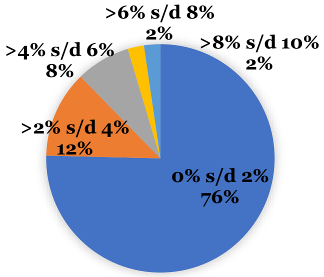
4.1.1. Data Collection Results

The data collected from the Sungai Duren-Sungai Buluh Road section in Jambi Province consisted of accident data, road geometric data from as-built drawings, and road safety attribute data from field surveys. These data were organized into a segment-based database to support Poisson regression analysis and iRAP Star Rating assessment. The distribution of road geometric variables and safety attributes is presented in Table 7.

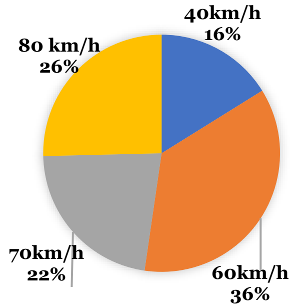
Table 7. Research Data Distribution

Data Diagram	Data Diagram	Data Diagram
		
Hilliness (m/km) - Flat (<10 m/km) - Moderate (10-30 m/km), - High (>30 m/km) - (IHCM, 1997)	Bendiness (°/km) - Straight (<50°/km) - Moderate (≥50°/km-<150°/km) - Sharp (≥150°/km) (Waka Kotahi New Zealand Transport Agency, 2025)	Road Lane Width (m) - Very Wide (≥2.5 m) - Wide (≥2.25 m-<2.5 m) - Medium(≥2.0 m-<2.25 m) - Narrow (≥0 m-<2.0 m)

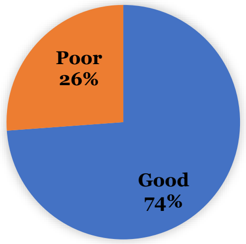
Data Diagram	Data Diagram	Data Diagram



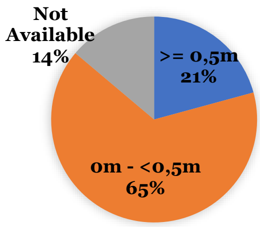
Superelevation (%)



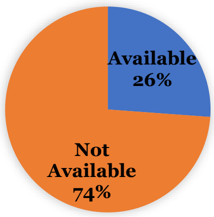
Operating Speed (km/h)



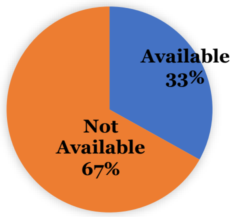
Pavement Condition



Road Shoulder



Street Lighting



Berm Availability

As shown in Table 7, the Sungai Duren-Sungai Buluh Road section has varied geometric and safety characteristics. Most segments were classified as flat based on hilliness and straight based on bendiness; however, several segments still had higher gradients and sharper curves. Infrastructure attributes, including lane width, superelevation, pavement condition, shoulder condition, street lighting, and berm availability, also varied across segments. These variations are important to analyze because they may influence accident risk and road safety levels.

4.1.2. Effect of Road Geometric Factors on Accident Frequency

The effect of road geometric factors on accident frequency was analyzed using Poisson regression in SPSS. This model was used because the dependent variable was count data, namely the number of traffic accidents in each road segment. Before model interpretation, a goodness-of-fit test was conducted to ensure the suitability of the Poisson regression model and to detect any indication of overdispersion. The results are presented in Table 8.

Table 8. Goodness-of-Fit Results of the Poisson Regression Model

Indicator	Value	df	Value/df	Interpretation
Deviance	87.763	120	0.731	No overdispersion indication
Pearson Chi-Square	118.460	120	0.987	Model is acceptable

As shown in Table 8, the Deviance/df and Pearson Chi-Square/df values were close to 1, indicating that the Poisson regression model was suitable for the analysis. In Poisson regression, a value divided by degrees of freedom close to 1 indicates an acceptable model, while a much higher value may indicate overdispersion (Cameron & Trivedi, 2013; Payne et al., 2018). If the equidispersion assumption is not met, an alternative model such as negative binomial regression may be considered (Hilbe, 2014). Therefore, the goodness-of-fit results confirm that the Poisson model was appropriate for explaining the effect of road geometric factors on accident frequency.

Table 9. Poisson Regression Results of Road Geometric Factors on Accident

Variable	B	Std. Error	Sig.	Exp(B)	Interpretation
Intercept	-4.893	1.5034	0.001	0.007	Constant
Hilliness (m/km)	0.021	0.0080	0.007	1.022	Positive significant effect
Bendiness (°/km)	0.008	0.0040	0.042	1.008	Positive significant effect
Operating Speed (km/h)	0.041	0.0197	0.038	1.042	Positive significant effect

The final Poisson regression results show that hilliness, bendiness, and operating speed significantly affected accident frequency. The parameter estimation results are presented in Table 9. Based on the table, all variables had significance values below 0.05, indicating significant effects on the dependent variable (Di Leo & Sardanelli, 2020). The positive coefficients show that increases in hilliness, bendiness, and operating speed tend to increase accident frequency. In addition, the Exp(B) values of all three variables were greater than 1, indicating that each increase in these variables increased the accident frequency ratio. Based on the parameter estimates, the Poisson regression model is formulated as follows:

$$\ln(\lambda_i) = -4.893 + 0.021X_1 + 0.008X_2 + 0.041X_3$$

or in exponential form:

$$\lambda_i = e^{-4.893+0.021X_1+0.008X_2+0.041X_3}$$

Where:
λ_i = estimated number of accidents in segment i
X_1 = hilliness
X_2 = bendiness
X_3 = operating speed

These results indicate that hilliness, bendiness, and operating speed are important geometric and operational factors influencing accident frequency on the Sungai Duren-Sungai Buluh Road section in Jambi Province. Therefore, road safety improvements should prioritize gradient conditions, road curvature, and speed management on high-risk segments.

4.1.3. Effect of Road Berm on Accident Frequency

The road berm analysis was conducted to compare the effects of geometric and operational factors on accident frequency between segments with and without berms. In road safety analysis, a berm or shoulder is an important part of the road cross-section that provides lateral clearance, emergency stopping space, and recovery area when vehicles deviate from the travel lane. Therefore, berm availability is relevant to accident risk because it can improve roadside safety, support vehicle recovery, and reduce the potential severity of run-off-road crashes, particularly on two-lane undivided roads (Department of Transportation, 2009; Dirjen Bina Marga, 2021).

Table 1. Summary of Poisson Regression Results Based on Berm Availability

Segment Category	Variable	B	Sig.	Exp(B)	Interpretation
With berm	No significant variable	-	> 0.05	-	Geometric and operational variables are not significant
Without berm	Pavement condition	1.037	0.063	2.821	Significant at the 10% significance level

Segment Category	Variable	B	Sig.	Exp(B)	Interpretation
Without berm	Hilliness	0.031	0.001	1.031	Positive and significant effect
Without berm	Operating speed	0.052	0.041	1.054	Positive and significant effect

As shown in Table 10, no variable significantly affected accident frequency on segments with berms, as all significance values were above 0.05. However, on segments without berms, hilliness and operating speed had significant effects, while pavement condition was marginally significant at the 10% level. This indicates that segments without berms are more sensitive to road gradient, vehicle speed, and pavement surface condition, suggesting that berm availability may help reduce geometric and operational accident risks (Di Leo & Sardanelli, 2020).

Table 11. Comparison of Pseudo R2 Values of the Poisson Regression Model

Model	Nagelkerke	McFadden
Main geometric model	0.236	0.148
Model with berm analysis	0.360	0.235

Based on Table 11, the model incorporating berm availability produced higher Pseudo R-Square values than the main geometric model. Although Pseudo R-Square is not interpreted in the same way as the coefficient of determination in linear regression, it can be used as a relative indicator of model fit in non-linear regression models (Cox & Snell, 1989; McFadden, 1974; Menard, 2000; Nagelkerke, 1991). Therefore, the increase in Pseudo R-Square values indicates that berm availability improves the model's explanatory ability for variations in accident frequency. Based on the Poisson regression results for segments without berms, the model is formulated as follows:

$$\ln(\lambda_i) = -6.055 + 1.037X_1 + 0.031X_2 + 0.052X_3$$

or in exponential form:

$$\lambda_i = e^{-6.055+1.037X_1+0.031X_2+0.052X_3}$$

Where:
λ_i = estimated number of accidents in segment i
X_1 = pavement condition
X_2 = hilliness
X_3 = operating speed

The model shows that higher pavement condition scores, hilliness, and operating speed tend to increase accident frequency on segments without berms. This suggests that berm availability is an important safety element because its absence makes road segments more vulnerable to geometric and operational risks.

4.1.4. Road Safety Level Based on iRAP Star Rating

The safety level of the Sungai Duren-Sungai Buluh Road section was assessed using the iRAP Star Rating method, referring to the Directorate General of Bina Marga guideline on Roadworthiness Testing with Star Rating. This method evaluates road safety risk based on physical and operational attributes, including road geometry, speed, shoulder condition, roadside condition, safety facilities, and the surrounding road environment. In the iRAP system, a 1-star road represents the highest safety risk, while a 5-star road represents the safest condition (Dirjen Bina Marga, 2024; iRAP, 2024). The assessment was conducted on 130 road segments, each 100 m long.

Table 2. Road Safety Level and Accident Distribution Based on iRAP Star Rating

Star Rating	Risk Level	Number of Segments
1 Star	Very high risk	70
2 Stars	High risk	40
3 Stars	Moderate risk	18
4 Stars	Low risk	2
5 Stars	Very low risk	0

Table 12 shows that the Sungai Duren-Sungai Buluh Road section is dominated by low safety ratings. Most segments were classified as 1 Star and 2 Stars, indicating very high to high safety risk. Only a small number of segments achieved 3 Stars and 4 Stars, while no segment reached 5 Stars. This indicates that the road section still requires priority infrastructure improvements, especially on segments with 1-star and 2-star ratings.

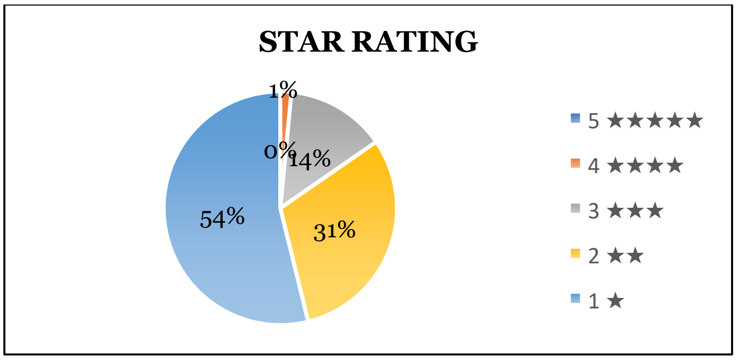


Figure 5. Distribution of Road Safety Level Percentage

Figure 6 further shows that accidents were concentrated on lower-rated segments. A total of 29 out of 33 accidents, or approximately 84.6%, occurred on 1-star and 2-star segments. This pattern suggests that road sections with higher infrastructure-related risks and tend to potentially increase accidents. However, this relationship should be interpreted as indicative rather than directly causal. Nevertheless, the pattern is consistent with the iRAP principle that lower Star Ratings indicate higher risks of fatal and serious injuries (Figure 6) Therefore, iRAP Star Rating can complement historical accident data in identifying high-risk road segments.

Figure 6. Relationship Between iRAP Star Rating and Accident Frequency

4.1.5. Road Infrastructure Improvement Recommendations

Road infrastructure improvement recommendations were developed by integrating the Poisson regression results and iRAP Star Rating assessment. The regression results identified hilliness, bendiness, and operating speed as significant factors affecting accident frequency, while the berm analysis highlighted the influence of hilliness, operating speed, and pavement condition on segments without berms. Since most segments also showed low safety performance in the iRAP assessment, the recommendations were formulated based on both accident frequency and physical road attributes that contribute to safety risk (Dirjen Bina Marga, 2024; iRAP, 2024).

Table 13. Road Infrastructure Improvement Recommendation Matrix

Analysis Basis	Main Issue	Improvement Recommendation	Expected Impact
Poisson regression	High hilliness	Speed control and vertical alignment improvement	Lower loss-of-control risk
Poisson regression and iRAP	High bendiness	Curve, sign, delineation, and superelevation improvement	Lower run-off-road risk
Poisson regression	High operating speed	Speed limit and speed control measures	Lower accident risk
Road geometry and iRAP	Narrow lanes	Lane widening	Improved vehicle clearance
Berm analysis and iRAP	Limited shoulder/berm	Paved shoulder or berm provision	Recovery space available
iRAP attributes	Poor delineation and lighting	Road marking, delineation, and lighting improvement	Better visibility
iRAP attributes	Low skid resistance	Pavement surface improvement	Better vehicle control
iRAP attributes	No textured markings	Textured edge and center markings	Better lane-departure warning

As shown in Table 13, the proposed improvements focus on road attributes supported by both the statistical findings and the iRAP assessment. Speed management is a key priority because operating speed significantly affected accident frequency. Other recommended measures include curve improvement, lane widening, paved shoulder or berm provision, improved delineation, street lighting, pavement surface improvement, and textured road markings. These interventions are expected to improve road geometry, visibility, recovery space, and vehicle stability, thereby reducing serious and fatal crash risks (Dirjen Bina Marga, 2024; iRAP, 2024; Turner et al., 2010).

To evaluate the potential effectiveness of the recommendations, an improvement simulation was conducted on a low-rated segment, namely KM 18+200-KM 18+300.

Table 14. Segment KM 18+200-KM 18+300 Road Section

Data	Description
Road assessment segment	KM 18+200-KM 18+300
Segment length	100 m
Number of accidents	1
Road gradient	40.8m/km
Bendiness	242.04°/km
Operating speed	40 km/h

Data	Description
Star Rating Score	48.90
Star Rating	1 Star

As shown in Table 14, the segment had a low initial safety level and required interventions related to curve quality, speed control, delineation, and other road safety attributes.

Table 15. Before and After Simulation of Road Infrastructure Improvement

Road Safety Attribute	Before Improvement	After Improvement
Operating speed	40 km/h	30 km/h
Speed limit differentiation	Not available	Available
Speed control engineering	Not available	Available
Lane width	Narrow	Moderate
Curve quality	Inadequate	Adequate
Horizontal curve	Very sharp	Sharp
Skid resistance	Moderate	Adequate
Delineation	Poor	Adequate
Street lighting	Not available	Available
Paved shoulder width	Not available	0 m to < 1 m
Textured edge marking	Not available	Available
Textured center marking	Not available	Available
Pavement condition	Adequate	Adequate
Star Rating Score	48.90	3.92
Star Rating	1 Star	4 Stars

Based on Table 15, he proposed improvements substantially enhanced the road safety level, reducing the Star Rating Score from 48.90 to 3.92 and improving the segment from 1 Star to 4 Stars. This indicates that targeted infrastructure interventions can effectively reduce safety risk and should be prioritized gradually on 1-star and 2-star segments along the Sungai Duren-Sungai Buluh Road section.

4.2. Discussion

The findings indicate that road geometric and operational characteristics significantly influence accident frequency on the Sungai Duren-Sungai Buluh Road section. The Poisson regression results show that hilliness, bendiness, and operating speed have positive and significant effects on accident frequency. This means that segments with greater elevation variation, sharper curvature, and higher operating speeds tend to have a higher accident risk. These findings are consistent with Putri et al. (2025), who found that hilliness and bendiness influence accident occurrence on curved road sections, and Leni et al. (2020), who reported that speed, traffic heterogeneity, and road geometry are associated with accident and fatality risk on inter-urban roads. Similarly, emphasized that geometric components should be considered important indicators in road accident risk analysis (Suraji & Mulyono, 2022). From a safety perspective, steep gradients may increase braking demand, sharp curves may reduce sight distance and vehicle stability, and higher speeds may reduce driver reaction time.

The berm analysis further shows that segments without berms are more vulnerable, particularly due to hilliness, operating speed, and pavement condition. This suggests that berms or shoulders play an important role as recovery space and safety buffers when vehicles deviate from the travel lane. The iRAP Star Rating results also support the statistical findings by showing that most segments were classified as 1-star and 2-star roads, indicating a relatively low level of infrastructure safety. Accidents were also more concentrated on lower-rated segments, suggesting that poor physical road conditions are associated with higher accident frequency. However, this relationship should be interpreted as indicative rather than directly causal, because accident frequency in each rating category is also influenced by the number of segments. Overall, integrating Poisson regression and iRAP Star Rating provides a stronger basis for identifying high-risk segments and formulating data-driven infrastructure improvements, particularly on segments with high hilliness, high bendiness, limited berm availability, inadequate pavement condition, and insufficient safety facilities.

5. Conclusion

This study analyzes the effect of road geometric factors on accident frequency and assessed the safety level of the Sungai Duren-Sungai Buluh Road section in Jambi Province. The Poisson regression results showed that hilliness, bendiness, and operating speed had significant positive effects on accident frequency. This indicates that greater elevation variation, sharper road curvature, and higher operating speed tend to increase accident risk. The berm analysis also showed that segments without berms were more vulnerable, particularly due to hilliness, operating speed, and pavement condition. Therefore, berm availability can be considered an important roadside safety element that helps reduce the sensitivity of road segments to geometric and operational risks.

The iRAP Star Rating assessment showed that the studied road section had a relatively low safety level, with most segments classified as 1-star and 2-star roads. Accidents were also more concentrated on lower-rated segments, indicating that poor physical road safety conditions were consistent with the observed accident pattern. Based on the integration of Poisson regression and iRAP assessment, the recommended improvements include speed management, curve quality improvement, lane widening, paved shoulder or berm provision, pavement surface improvement, improved delineation, street lighting, and textured road markings. The improvement simulation showed that the Star Rating could increase from 1 Star to 4 Stars, demonstrating that targeted infrastructure interventions can substantially improve road safety. Therefore, these recommendations should be prioritized on low-rated segments to enhance safety performance and reduce accident risk along the Sungai Duren-Sungai Buluh Road section.

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5.2. Competing interests

The author declares that there are no competing interests related to this study.

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