Equivalent: Jurnal Ilmiah Sosial Teknik
Volume 8, Issue 3, 927-944
e_ISSN: 2775-0833
https://jurnalequivalent.id/index.php/jequi/index
DOI: doi.org/10.59261/jequi.v8i3.338

Road Safety Study in Accident-Prone Areas on the Gading - Playen and Yogyakarta - Barongan Road Sections

Raafi Widyaputra Yulianyahya*
Universitas Esa Unggul, Indonesia

Ghefra Rizkan Gaffara
Universitas Esa Unggul, Indonesia

Ansadilla Niar Sitanggang
Universitas Esa Unggul, Indonesia

Irma Damayantie
Universitas Esa Unggul, Indonesia

***Corresponding author:**
Raafi Widyaputra Yulianyahya, Universitas Esa Unggul, Indonesia.
✉raafi.widyaputra@esaunggul.ac.id

Article Info:
Article history:
Received: May 11, 2026
Revised: June 18, 2026
Accepted: July 04, 2026

Keywords:
Road Safety; Accident-Prone Areas; Infrastructure; Education; Driver Behavior.

Abstract

Background: The background of this research stems from the high number of accidents occurring on this road section, which endangers the safety of road users.
Objective: This study aims to analyze traffic safety on two road sections with high accident rates, namely the Gading–Playen Road and the Yogyakarta–Barongan Road.
Methods: The research methods employed include field surveys, collection of primary and secondary data, and statistical analysis using the CUSUM method and the V/C (volume-to-capacity) ratio.
Results: The analysis revealed Gading–Playen Road section has a capacity of 3,354 pcu/hour with a V/C ratio of 0.196, indicating stable traffic conditions, while the Yogyakarta–Barongan Road section has a capacity of 3,444 pcu/hour with a V/C ratio of 0.771, reflecting near-saturated traffic conditions and a higher-risk situation. Z-score analysis of accident data from 2016 to 2019 showed a sharp spike on the Yogyakarta–Barongan section in the third period (z = +1.55), while the Gading–Playen section recorded a significant decline (z = −1.13). Accidents on both sections predominantly involve motorcycle users and male victims aged 16–25 years, and are primarily caused by undisciplined driving behavior. Key recommendations include geometric road improvements, installation of adequate traffic signs, improved road lighting, and strengthened enforcement of traffic regulations.
Conclusion: The integration of CUSUM, Z score, and V/C ratio methods provides an effective framework for identifying and assessing traffic accident risks. The findings reveal distinct risk characteristics between road sections, requiring targeted interventions based on geometric conditions, traffic intensity, and behavioral factors.

To cite this article: Yulianyahya, R. W., Gaffara, G. R., Sitanggang, A. N., & Damayantie, I. (2026). Road Safety Study in Accident-Prone Areas on the Gading - Playen and Yogyakarta - Barongan Road Sections. *Equivalent: Jurnal Ilmiah Sosial Teknik*, 8(3), 927-944. https://doi.org/10.59261/jequi.v8i3.338

INTRODUCTION

Road safety is an important element in the development of transportation strategies designed to protect people on the road from potential accidents. The World Health Organization (WHO) states that traffic accidents are among the leading causes of death worldwide, making it crucial to address this issue promptly (Organization, 2020, 2023). In Indonesia, traffic accidents are one of the biggest problems, with death rates increasing every year (Kalae et al., 2025; Syahriza, 2019). One of the main contributing factors to accidents is road infrastructure that does not meet safety standards, as well as undisciplined driver behavior (Elvik et al., 2009; Organization, 2023).

The Gading–Playen Road section (2.95 km, Provincial Road No. 045, Gunung Kidul Regency) and the Yogyakarta–Barongan Road section (9.80 km, Provincial Road No. 002, Bantul Regency) are two road segments with documented histories of traffic accidents. The Gading–Playen section recorded 12, 14, and 2 accident events in the periods 2016–2017, 2017–2018, and 2018–2019 respectively, ranking 2nd, 1st, and 73rd at the regional level in the corresponding years. The Yogyakarta–Barongan section is more critical, with 57, 32, and 114 accident events across the same periods, consistently ranking 1st or 2nd at the regional level. In terms of road infrastructure, the Gading–Playen section has a lane width of only 5.1 m, which is relatively narrow for its secondary collector function, with documented geometric deficiencies including substandard curve radii and inadequate superelevation. The Yogyakarta–Barongan section, while wider at 10.7 m, also exhibits mismatched horizontal and vertical alignments, inconsistent superelevation, and high traffic density. Both sections are located in mixed residential environments, where driver behavior, environmental conditions (visibility and lighting), and road geometric design jointly contribute to accident risk (Harianto, 2019; Kalae et al., 2025; Samsudin, 2020).

Previous research shows that infrastructure improvements and the implementation of effective control systems can reduce accident rates (Harianto, 2019; Kalae et al., 2025; Samsudin, 2020). However, in many areas of Indonesia, including the road sections that are the focus of this research, road infrastructure conditions still do not meet safety standards, and driver behavior often disregards traffic regulations (Kalae et al., 2025; Samsudin, 2020). This makes road safety an important issue that needs to be addressed immediately.

Research also shows that well designed infrastructure can significantly reduce accident rates (Elvik et al., 2009; Organization, 2023). Therefore, it is crucial for stakeholders in transportation to design roadways with an emphasis on public health and safety. In developed countries, road safety is a high priority to reduce the frequency of accidents. The government is obliged to guarantee the protection of road users and prevent accidents as part of its responsibility in overseeing the road system (Indonesia, 2021; Simanungkalit, 2022).

To achieve these objectives, various strategic steps need to be taken. Therefore, the government must pursue strategic management approaches, both in the form of policies and practical field measures, so that traffic accident problems can be handled comprehensively (Transportasi, 2004). It is expected that authorities will implement these strategies through both regulations and practical interventions to reduce traffic accidents. The increasing number of traffic accidents each year in Indonesia contributes to the rising number of fatalities in society (Kalae et al., 2025; Syahriza, 2019).

Traffic accidents are a problem that requires thorough investigation. Therefore, it is very important to conduct an examination by reviewing existing traffic accident statistics. This examination aims to determine areas with a high probability of accidents (black spots) by evaluating the number of fatal accidents or Traffic Fatalities (TF) and the Upper Control Limit (UCL) threshold value. Various contributing factors include human (driver) behavior, environmental conditions, vehicles, and road characteristics (Harianto, 2019; Kalae et al., 2025; Samsudin, 2020).

Traffic accidents are a problem that requires thorough investigation. Therefore, it is very important to conduct an examination based on accident statistics to determine locations with high accident potential (black spots) through evaluating the number of fatal accidents or Traffic Fatalities (TF) and the Upper Control Limit (UCL) threshold value; furthermore, accidents are influenced by various factors such as humans (drivers), the environment, vehicles, and road characteristics. Based on this background, the problem formulation in this research is how to quantitatively identify accident prone locations (black spots) on both road sections and to what extent road geometric design and traffic facilities contribute to the occurrence of accidents.

This research adopts existing approaches in the literature, such as the CUSUM (Cumulative Sum) method for identifying accident prone points, which has been applied in several previous studies. However, the novelty of this research lies in the integration of the CUSUM method with the V/C ratio (Volume to Capacity ratio) to dynamically assess road capacity loading. This method has not been widely applied in Indonesia and will provide a deeper analysis of road section performance (Goel et al., 2024; Mohammed & Ali, 2021).

Despite the proliferation of road safety studies in Indonesia, several critical methodological gaps remain inadequately addressed in the existing literature. First, most prior studies in the Indonesian context rely exclusively on either statistical frequency based approaches (e.g., z score or rate quality control) or engineering based measures (e.g., V/C ratio and geometric assessment) in isolation, without integrating both dimensions into a unified framework. For example, Harianto and Radam (2019) and Samsudin (2020) focused primarily on infrastructure factors, while Syahriza (2019) emphasized epidemiological accident trends, none of which incorporated traffic flow performance metrics (Kalae et al., 2025). Second, the use of the CUSUM method for detecting persistent black spots, which is sensitive to the duration and onset of elevated accident risk rather than mere frequency, has received limited application in Indonesia despite its demonstrated superiority for trend detection in traffic safety monitoring (Mekonnen & Sipos, 2022; Mitra & Washington, 2016). Third, the simultaneous integration of primary field data (community surveys and spot speed measurements) with quantitative statistical models remains rare in Indonesian road safety literature, limiting the practical applicability of findings. This study addresses these gaps by proposing and applying a combined CUSUM–V/C ratio framework supported by multi source primary data collection.

Furthermore, this research also combines primary data obtained through field surveys and interviews with the community, which is rarely done in similar studies. This provides more relevant recommendations based on local conditions, such as the need for improvements to traffic signs and road lighting. This research also proposes multidimensional interventions, combining road infrastructure improvements, law enforcement through electronic ticketing, and public education as a more comprehensive approach to reducing accidents. This research is expected to make a significant contribution to the development of more effective road safety policies in Indonesia, particularly in addressing traffic accident problems in accident prone areas.

METHOD

This research used a descriptive quantitative approach supported by field analysis and technical interpretation of road safety. The research objective was to identify accident prone locations (black spots) on the Gading–Playen and Yogyakarta–Barongan road sections, and to analyze the factors contributing to the high accident rates on these two sections. This method was designed to align with the research objectives, targeted outputs, and the integration of results into learning outcomes.

The research stages began with a literature review of transportation safety theory, the concept of black spots, traffic accident analysis methods, and technical regulations related to road geometry and traffic equipment. At this stage, a review of previous research findings was also conducted to determine relevant analysis indicators, such as Average Daily Traffic (LHR), vehicle spot speed, road geometric characteristics, and accident causal factors. The results of the literature review served as the basis for preparing observation instruments, data collection formats, and analysis frameworks.

The next stage was the collection of primary and secondary data. Primary data were obtained through field surveys, including traffic volume counting, vehicle spot speed measurements, observation of road geometric conditions, inventory of road equipment, visual documentation, and brief interviews with relevant parties and road users. Secondary data were obtained from relevant agencies, such as traffic accident data, supporting information on road section conditions, and previous traffic data. Data collection was conducted at points identified as having a high level of accident risk based on incident records and the physical conditions of the road sections.

After data collection, the data processing and validation stage was carried out. Field survey data were checked for completeness, classified by variable type, and then recapitulated in table format to facilitate analysis. Validation was carried out by comparing selected field data with secondary data and conducting limited re surveys to ensure the error rate remained low. This stage was important to ensure that the analysis results accurately reflected actual field conditions.

Data analysis was conducted in two forms. First, quantitative statistical analysis was used to identify black spot locations using the accumulation of accident events and statistical control indicators such as CUSUM and Z score, so that points with a high tendency for accidents could be identified more objectively. Second, descriptive technical analysis was conducted by examining the relationship between accident events and road geometric conditions, traffic volume, vehicle speed, lighting, signage, road markings, and the surrounding environment. The results of both analyses were then used to formulate applicable technical recommendations.

Regarding data collection instruments, the primary survey used a handheld tally counter and video camera for traffic volume counting at designated survey points, a stopwatch and measuring tape for spot speed measurements using the time–space method over a 50 meter trap length, and a structured questionnaire for community interviews. Traffic counting was conducted over two days (one weekday and one holiday) with eight observation periods of one hour each (07:00–08:00, 08:00–09:00, 11:00–12:00, 12:00–13:00, 13:00–14:00, 15:00–16:00, 16:00–17:00, and 17:00–18:00 UTC+7). Spot speed surveys were conducted at three representative points per section, with a minimum sample of 30 vehicles per vehicle class. The city size factor (F_uK) and the types and frequency of side friction events were also recorded as secondary parameters for capacity calculation adjustment factors in accordance with PKJI 2023.

RESULTS AND DISCUSSION

Analysis Results

Average Daily Traffic (LHR) Data

LHR data on the Gading–Playen and Yogyakarta–Barongan road sections can be seen in Table 1. This is an important metric that represents the number of vehicles passing a specific point on the road in a day; this information is crucial for infrastructure planning, traffic management, and road safety improvements (Sharma & Gupta, 2020; Sharma & Choudhary, 2026).

Table 1. LHR Survey Data for Gading Playen Road Section

Day	Time (UTC+7)	Vehicle Type			Total
		MC	LV	HV	
Weekday	07:00-08:00	797	74	22	893
	08:00-09:00	714	122	37	873
	11:00-12:00	524	119	31	674
	12:00-13:00	514	141	33	688
	13:00-14:00	411	137	43	591
	15:00-16:00	502	132	23	657
	16:00-17:00	700	161	27	888
	17:00-18:00	531	155	24	710
Holiday	07:00-08:00	474	152	13	639
	08:00-09:00	604	158	42	804
	11:00-12:00	359	165	11	535
	12:00-13:00	515	217	22	754
	13:00-14:00	580	187	41	808
	15:00-16:00	577	196	31	804
	16:00-17:00	674	244	59	977
	17:00-18:00	695	200	36	931

Source: Reseach Data

The LHR fluctuation diagram for the Gading Playen Road section on weekdays and holidays is presented in Figure 1.

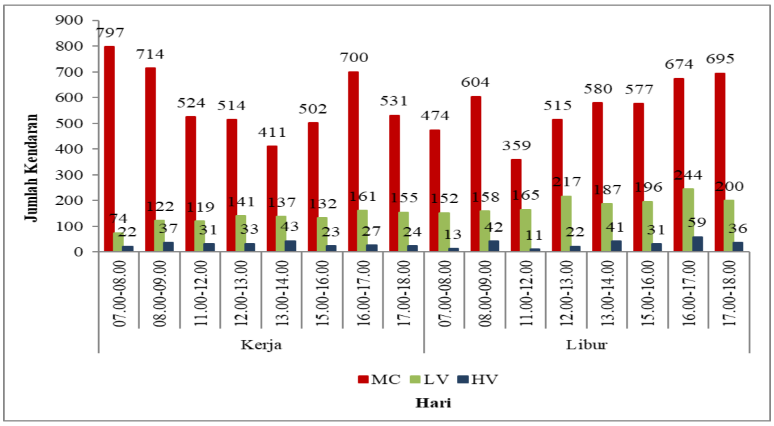


Figure 1. LHR Fluctuation Diagram for Gading Playen Road Section
Source: Reseach Data

Figure 1 shows that on weekdays, the Gading–Playen Road section experiences two distinct peak periods: the morning peak (07:00–08:00), driven by commuter and school related travel, and the afternoon peak (16:00–17:00), associated with return journeys from work. The midday period (11:00–14:00) shows a moderate decline in traffic volume, reflecting reduced non work related mobility. On holidays, the morning peak shifts to 08:00–09:00, suggesting later departure patterns, while traffic volume increases between 12:00 and 17:00, reflecting leisure oriented travel. These bidirectional peak patterns are consistent with typical traffic distribution on rural collector roads in Indonesia (Sharma & Gupta, 2020; Sharma & Choudhary, 2026).

Table 2. LHR Survey Data for Yogyakarta Barongan Road Section

Day	Time (UTC+7)	Vehicle Type			Total
		MC	LV	HV	
Weekday	07:00-08:00	3390	551	32	3973
	08:00-09:00	2769	625	42	3436
	11:00-12:00	2024	773	43	2840
	12:00-13:00	2271	722	40	3033
	13:00-14:00	2284	718	23	3025
	15:00-16:00	2694	791	34	3519
	16:00-17:00	3727	760	26	4513
	17:00-18:00	2836	659	15	3510
Holiday	07:00-08:00	4000	582	49	4631
	08:00-09:00	2888	686	53	3627
	11:00-12:00	2393	899	60	3352
	12:00-13:00	2544	928	63	3535
	13:00-14:00	2815	866	63	3744
	15:00-16:00	2436	633	37	3106
	16:00-17:00	3423	735	53	4211
	17:00-18:00	3383	865	42	4290

Source: Reseach Data

The LHR fluctuation diagram for the Yogyakarta Barongan Road section on weekdays and holidays is presented in Figure 2.

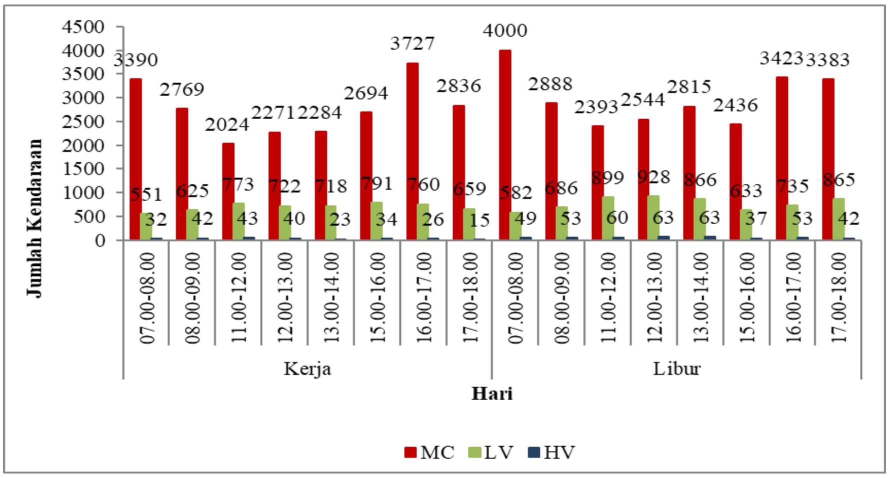


Figure 2. LHR Fluctuation Diagram for Yogyakarta Barongan Road Section
Source: Reseach Data

Figure 2 illustrates that on weekdays, the Yogyakarta–Barongan Road section experiences its highest traffic volume during the afternoon peak period (16:00–17:00 UTC+7, reaching 4,513 vehicles/ hour), reflecting intense commuter return movements. On holidays, the highest volume occurs in the morning (07:00–08:00 UTC+7, reaching 4,631 vehicles/hour), likely driven by leisure and long distance travel. The consistently higher traffic volumes on the Yogyakarta–Barongan section compared to the Gading–Playen section reinforce its function as a primary inter urban corridor. High traffic volumes during peak hours are known to increase vehicle interaction probability and thereby elevate accident risk (WHO, 2020).

Based on the peak vehicle flow, the total traffic flow can be converted into passenger car units (PCU) using passenger car equivalent (emp) factors as specified in the Indonesian Road Capacity Guidelines (*Pedoman Kapasitas Jalan Indonesia, PKJI*) (Jenderal et al., 2023): Motorcycle (MC) = 0.5, Light Vehicle (LV) = 1.0, and Heavy Vehicle (HV) = 1.3. The resulting total traffic flow in passenger car units (PCU/hour) for the Gading–Playen and Yogyakarta–Barongan road sections is presented in Table 3 and Table 4.

Table 3. Total Vehicle Flow on Gading Playen Road Section

Day	Time (UTC+7)	Total Flow (Q) (pcu/hour)
Weekday	07:00–08:00	501
Holiday	16:00–17:00	658
Total		1159

Source: Reseach Data

Table 4. Total Vehicle Flow on Yogyakarta – Barongan Road Section

Day	Time (UTC+7)	Total Flow (Q) (pcu/hour)
Weekday	16:00–17:00	2657
Holiday	07:00–08:00	2646
Total		5303

Source: Reseach Data

The total flow data in Table 4 shows that the peak hour on weekdays occurs at 07:00–08:00 UTC+7, with a vehicle volume reaching 501 PCU/h, while on holidays it occurs at 16:00–17:00 UTC+7, with a vehicle volume reaching 658 PCU/h. From these two conditions, the peak flow selected for the degree of saturation analysis on the Gading–Playen Road section occurs during holidays.

Furthermore, the total flow data in Table 5 shows that the peak hour on weekdays occurs at 16:00–17:00 UTC+7, with a vehicle volume reaching 2,657 PCU/h, while on holidays it occurs at 07:00–08:00 UTC+7, with a vehicle volume reaching 2,646 PCU/h. From these two conditions, the peak flow selected for the degree of saturation analysis on the Yogyakarta–Barongan Road section occurs during weekdays.

Spot Speed Data

Spot speed data are used to determine the instantaneous speed of vehicles. The average spot speed values for the Gading–Playen and Yogyakarta–Barongan Road sections are presented in Table 6 and Table 7. Spot speed measurement is an important method in traffic analysis used to determine vehicle speed at specific points along a road, which plays a crucial role in evaluating geometric road design and traffic safety (Elvik et al., 2009; Organization, 2023). Measurement methods generally use technologies such as radar or laser devices to obtain accurate data under various traffic conditions (Schweppenhäuser et al., 2025). Additionally, spot speed data are useful for understanding driver behavior and vehicle speed by vehicle type, where heavy vehicles typically travel at lower speeds compared to light vehicles (da Silva & Cavalcante, 2025). Thus, the spot speed data in this study provide an important overview of instantaneous vehicle speeds that supports traffic policy making and more effective road design.

Table 6. Spot Speed Data for Gading Playen Road Section

Road Length	**Speed (km/h)**		
	MC	**LV**	**HV**
2,95 km	48	57	32
	42	58	31
	59	29	28
Average	50	48	30

Source: Reseach Data

Table 7. Spot Speed Data for Yogyakarta Barongan Road Section

Road Length	**Speed (km/h)**		
	MC	**LV**	**HV**
9.8 km	39	33	28
	39	36	34
	44	37	24
Average	41	35	29

Source: Reseach Data

Road Capacity Analysis

Capacity, according to PKJI 2023, is defined as the maximum traffic flow that can be accommodated on a road segment or intersection under specific conditions (geometry, traffic composition, directional distribution, and environmental factors), as shown in Equation 1.

$$C = C_O \times FC_L \times FC_{PA} \times FC_{HS} \quad (1)$$

Information:
C = segment capacity (pcu/hour)
C_O = basic segment capacity (pcu/hour)
FC_L = capacity correction factor due to non ideal lane width
FC_{PA} = capacity correction factor due to directional split
FC_{HS} = capacity correction factor due to side friction and non ideal shoulder width

Based on Equation 1, the calculated capacities for the Gading–Playen Road section and the Yogyakarta–Barongan Road section are 3,354 pcu/hour and 3,444 pcu/hour, respectively. However, Table 4a presents a more detailed capacity calculation in accordance with PKJI 2023. For the Gading–Playen Road (2/2 UD, Secondary Collector, Small City), the parameters are: C_0 = 2,900 pcu/hour; FC_l = 0.87 (lane width 5.1 m); FC_p = 1.00; FC_{hs} = 0.96 (low side friction, 0.5 m shoulder); and F_{uk} = 0.86 (population < 500,000). The revised capacity is C ≈ 2,084 pcu/hour. For the Yogyakarta–Barongan Road (2/2 UD, Primary Collector, Large City/Yogyakarta Metropolitan), the parameters are: C_0 = 2,900 pcu/hour; FC_l = 1.00; FC_p = 1.00; FC_{hs} = 0.94; and F_{uk} = 1.00. The revised capacity is C ≈ 2,726 pcu/hour. These revised values incorporate the city size adjustment factor (F_{uk}), which was not included in the initial calculations, resulting in more accurate capacity estimates.

Degree of Saturation/VC Ratio Analysis

According to PKJI 2023 for Intercity Roads, the degree of saturation value indicates whether a road segment will have capacity issues or not, as shown in Equation 2.

$$D_J = q/C \quad (2)$$

Information:
q = traffic flow being evaluated for performance (pcu/hour)
C = road segment capacity (pcu/hour)

Based on Equation 2, the VC ratio value for the Gading Playen Road section is 0.196 and for the Yogyakarta Barongan Road section is 0.771.

Accident Data

Accident sample data from the DIY Regional Police, covering the period August 2016 to June 2019, were used to perform z score analysis on both road sections, providing insights into accident frequency and severity. Z score analysis is a statistical method used to identify outliers or unusual data points, which is crucial for understanding accident patterns and implementing safety measures. A study by Zhang et al. (2022) highlights the importance of considering various factors such as traffic volume, speed, and geometric characteristics in crash frequency analysis, which can also be applied in z score analysis to identify significant deviations in crash data (P. Zhang et al., 2022). Similarly, Geng et al. (2022) emphasize the use of advanced statistical methods such as extreme value theory to predict crash probabilities, aligning with the ability of z scores to highlight extreme values in crash data (Geng et al., 2022). Furthermore, Tang et al. (2021) discuss challenges in modeling crash frequency in expressway tunnels, noting the importance of addressing excess zero observations and unobserved heterogeneity, which are also relevant for refining z score analysis for more accurate accident data interpretation (Tang et al., 2021; Zhang et al., 2025). Collectively, these methodologies underscore the potential of z score analysis in identifying high risk areas and informing the development of targeted safety interventions on roads. Accident data are presented in Table 8.

Table 8. Accident Data for Gading Playen and Yogyakarta Barongan Road Sections

Year	Gading–Playen (number of accidents)	Yogyakarta–Barongan (number of accidents)
2016 – 2017	12	57
2017 – 2018	14	32
2018 – 2019	2	114

Source: Reseach Data

In 2016/2017, the Gading–Playen road ranked 2nd; in 2017/2018, it ranked 1st; and in 2018/2019, it ranked 73rd. The average accident victims were aged between 16–25 years and 51–60 years, with the dominant gender being male. Their occupation was employees. The most frequent time of accident occurrence was 06:00–12:00 Western Indonesia Time (UTC+7), and the road is located in a residential area on a national road. The causal factor for accidents was undisciplined driving. The motor vehicles involved were dominated by motorcycles.

In 2016/2017, the Yogyakarta–Barongan road ranked 1st; in 2017/2018, it ranked 2nd; and in 2018/2019, it ranked 1st. The average accident victims were aged between 16–25 years and 51–60 years, with the dominant gender being male. Their occupation was employees. The most frequent time of accident occurrence was 06:00–12:00 Western Indonesia Time (UTC+7), located in a residential area. The causal factor for accidents was undisciplined driving. The motor vehicles involved were dominated by motorcycles.

Accident prone locations were identified using a blackspot approach and evaluated by assessing weak points using blackspot techniques, as well as Z score analysis (Equation 3) for both road sections.

$$z = \frac{xx-\mu\mu}{\sigma\sigma} \qquad (3)$$

Information:
x = individual data value
μ = sample mean
σ = sample standard deviation

The z score evaluation presented in Equation 3 measures the extent to which a data point differs from the mean, expressed in units of standard deviation. A positive z score indicates a value above the mean, while a negative z score indicates a value below the mean. The larger the absolute z score value, the more extreme or unusual the data point is relative to the mean (Montgomery & Runger, 2010; Martin & Bombaerts, 2026). The description of z score values according to Equation 3 for the Gading–Playen and Yogyakarta–Barongan road sections is presented in Table 9 and Table 10.

Table 9. Description of Z Values for Gading   Playen Road Section

Year	Number of Accidents	Z score	Description
2016 – 2017	12	+0.41	Slightly higher than average; relatively normal condition
2017 – 2018	14	+0.72	Higher than average; small increase in accident numbers
2018 – 2019	2	1.13	Much lower than average; significant decrease in accident numbers

Source: Reseach Data

Table 10. Description of Z Values for Yogyakarta   Barongan Road Section

Year	Number of Accidents	Z score	Description
2016 – 2017	57	0.44	Slightly lower than average; relatively normal condition
2017 – 2018	32	1.11	Significantly lower compared to the previous year
2018 – 2019	114	+1.55	Very sharp increase and far above average, indicating a surge in accident risk

Source: Reseach Data

CUSUM (Cumulative Sum) Analysis

The CUSUM (Cumulative Sum) method is applied to detect persistent shifts in accident frequency above a threshold level, complementing the z score analysis by identifying the onset and duration of high risk periods. Following the standard formulation, the CUSUM statistic S_i is calculated as $S_i = \max(0, S_{i-1} + (x_i - \mu_0 - k))$, where x_i is the observed accident count in period i, μ_0 is the target (acceptable) mean accident rate, and k is the allowable slack (half the expected shift magnitude). An alert is triggered when S_i exceeds the decision threshold H (Mekonnen & Sipos, 2022; Mitra & Washington, 2016).

For the Gading–Playen Road section, using $\mu_0 = 9.33$ accidents/year (overall mean = (12 + 14 + 2)/3) and $k = 2$:

$S_1 = \max(0, 0 + (12 - 9.33 - 2)) = \max(0, 0.67) = 0.67$;

$S_2 = \max(0, 0.67 + (14 - 9.33 - 2)) = \max(0, 0.67 + 2.67) = 3.34$;

$S_3 = \max(0{,}3.34 + (2 - 9.33 - 2)) = \max(0{,}3.34 - 9.33) = 0.$

Using $H = 5$ as the decision threshold, no period exceeds H, confirming that the Gading–Playen section does not qualify as a persistent black spot over the study period, consistent with the declining accident trend observed in 2018–2019.

For the Yogyakarta–Barongan Road section, using $\mu_0 = 67.67$ accidents/year and $k = 15$:
$S_1 = \max(0{,}0 + (57 - 67.67 - 15)) = \max(0, -25.67) = 0;$
$S_2 = \max(0{,}0 + (32 - 67.67 - 15)) = \max(0, -50.67) = 0;$
$S_3 = \max(0{,}0 + (114 - 67.67 - 15)) = \max(0{,}31.33) = 31.33.$

The CUSUM value in period 3 (2018–2019) of $S_3 = 31.33$ far exceeds $H = 5$, triggering a black spot alert that confirms the Yogyakarta–Barongan section as a persistent high risk location. The sharp escalation in period 3 indicates a structural deterioration in road safety conditions rather than random variation, warranting immediate targeted intervention (Mekonnen & Sipos, 2022; Mitra & Washington, 2016).

Table 10a. CUSUM Analysis Results for Both Road Sections

Period	Year	Gading Playen Accidents	CUSUM (Si)	Yogya Barongan Accidents	CUSUM (Si)	Alert (H=5)?
1	2016 2017	12	0.67	57	0	No
2	2017 2018	14	3.34	32	0	No
3	2018 2019	2	**0**	114	**31.33**	**YES**

Source: Reseach Data

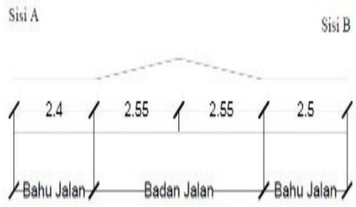
Note: μ_0 (target mean) = overall section mean; k (slack) = 2 (Gading Playen), 15 (Yogyakarta Barongan); H (threshold) = 5. = Black spot alert triggered.

Road Geometric Data

Road geometric data include various physical parameters important for assessing and improving road safety and performance. Key parameters include lane width, slope, curve radius, and pavement condition, each playing a crucial role in road safety and operational efficiency. For instance, lane width and curve radius are important factors affecting crash frequency on rural roads, as shown by crash prediction models developed for horizontal curve segments in Thailand (Kronprasert et al., 2021; Sum et al., 2026). Accurate road slope measurement is essential for applications such as fuel consumption estimation on forest roads, where technologies like GNSS and UAV based systems provide precise longitudinal profiles (Lepoglavec et al., 2023). Additionally, pavement condition, assessed through indices such as the Pavement Condition Index (PCI), significantly impacts traffic operational performance, affecting speed and capacity more than road geometry itself (Hashim et al., 2023). Advanced technologies such as the ROADS prototype system utilize unmanned ground vehicles to efficiently monitor pavement distress, offering a practical approach to maintaining road conditions (Mei et al., 2022). Collectively, these studies underscore the importance of integrating advanced measurement technologies and comprehensive data analysis to optimize road design, maintenance, and safety strategies. The road geometric analysis data on the Gading Playen and Yogyakarta Barongan Road sections is presented in Table 11 and Table 12.

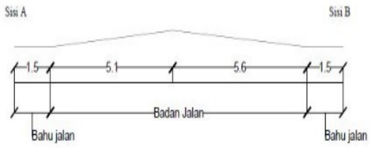
Table 11. Data for Gading Playen Road Section

Item	Description
Road No.	045
Road Name	Gading Playen
Road Status	Provincial Road
Location	Gunung Kidul Regency
Road Function	Secondary Collector

Item	Description
Road Type	2/2 UD
Road Length	2.95 km
Road Width	5.1 m
Documentation	
	
Geometric Road Analysis	
Effect of Geometry on Road Surface Quality	a. The main factor causing accidents and road surface damage on the Gading–Playen road section is the geometric design not meeting standards. b. Geometric parameters such as a lane width of only 5.1 m are relatively narrow for a secondary collector function, increasing vehicle conflict potential. c. Curves with small radii without speed adjustments cause excessive pressure on the asphalt surface, accelerating damage. d. Imbalance between horizontal and vertical alignments also affects vehicle load distribution, increasing the International Roughness Index (IRI) value. e. Suboptimal drainage due to inappropriate cross slopes or superelevation causes water pooling, accelerating pavement layer degradation.
Analysis of Horizontal and Vertical Alignment Intersection at Transition Curves	a. Ideally, a smooth transition between horizontal and vertical alignments should occur at transition curves. b. Field observations found mismatches between these alignments at several points on the Gading–Playen section: 1) Sudden elevation changes coinciding with changes in curve direction, 2) Reduced stopping sight distance due to combination of ascending/descending curves with turns, 3) Increased blind spot potential, 4) Higher water pooling risk if critical slopes are not considered in vertical design.
Field Superelevation Analysis	a. Ideal superelevation according to technical standards is approximately 2% 3%; however, field conditions indicate locations where superelevation values are still below this. b. Low superelevation values mean centrifugal force during cornering is not perfectly balanced by the road's cross slope, causing vehicles to tilt outward or slip, especially at high speeds.

Source: Reseach Data

Table 12. Data for Yogyakarta Barongan Road Section

Road No	**002**	**Road Name**	**Yogyakarta Barongan**
Road Status	Provincial Road	**Location**	Bantul Regency
Road Function	Primary Collector	**Road Type**	2/2 UD
Road Length	: 9,80 km	**Road Width**	: 10,7 m
Documentation			
			
Geometric Road Analysis			
Effect of Geometry on Road Surface Quality	a. The average speed of light vehicles in the field is approximately 35 km/h, relatively low compared to other road sections due to geometric conditions and traffic density. b. Suboptimal geometric design, such as small curve radii without safe speed adjustments, causes excessive pressure on the asphalt surface, accelerating surface damage and increasing the IRI value. c. Imbalance between horizontal and vertical alignments also affects vehicle load distribution, accelerating pavement layer degradation.		
Analysis of Horizontal and Vertical Alignment Intersection at Transition Curves	a. Ideally, a smooth transition between horizontal and vertical alignments should occur at transition curves. b. Field observations found mismatches between these alignments at several points on the Yogyakarta–Barongan section: 1) Sudden elevation changes coinciding with changes in curve direction, 2) Reduced stopping sight distance due to combination of ascending/descending curves with turns, 3) Increased blind spot potential, 4) Higher water pooling risk if critical slopes are not considered in vertical design.		
Field Superelevation Analysis	The ideal superelevation according to technical standards is approximately 2% 3%; however, actual conditions show locations where superelevation values are still below this or have not been applied consistently along the section.		

Source: Reseach Data

Respondent Survey Results

Feedback from respondents to questionnaire items regarding suggestions for reducing accidents is very important, as it reflects the community's experiences and perceptions of road conditions and contributing factors to crashes. Analysis of these suggestions can help authorities identify problems, improve safety measures, and build public awareness of the importance of participation in traffic safety improvement efforts (Goel et al., 2024; Mohammed & Ali, 2021). Respondents' questionnaire responses in the form of suggestions regarding accidents on the Gading–Playen Road section are presented in Table 13 and Figure 3.

Table 13. Community Respondent Results for Gading Playen Road Section

No.	Suggestion	Frequency	% Frequency
1	Provision of road complementary facilities (signs, lighting)	4	40.00
2	Road repairs	6	60.00
Total		**10**	**100.00**

Source: Reseach Data

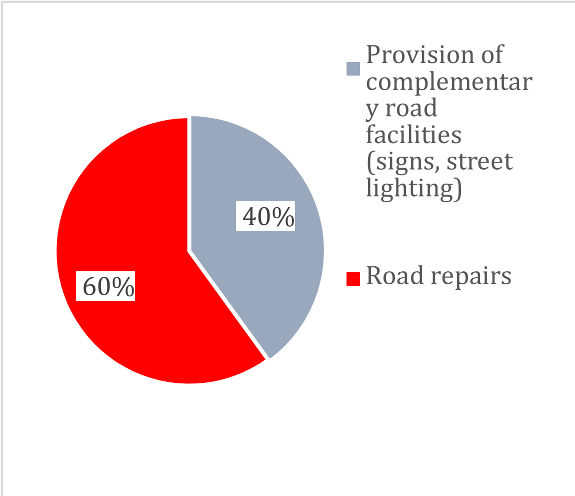


Figure 3. Diagram of Respondent Suggestions Regarding Traffic Accidents on Gading Playen Road
Source: Reseach Data

Based on the respondents' responses, it can be seen that the need for road repairs can reduce the potential for accidents. This was expressed by 60% of respondents. Furthermore, respondents' answers to the questionnaire items in the form of suggestions regarding accidents on the Yogyakarta–Barongan Road section are presented in Table 14 and Figure 4.

Table 14. Community Respondent Results for Yogyakarta Barongan Road Section

No.	Suggestion	Frequency	% Frequency
1	Stricter driving regulations	5	22.73
2	Provision of road complementary facilities (signs, lighting)	12	54.55
3	Pruning of trees around the road	1	4.55
4	Road repairs	2	9.09
5	Periodic maintenance of road complementary facilities	2	9.09
Total		**22**	**100.00**

Source: Reseach Data

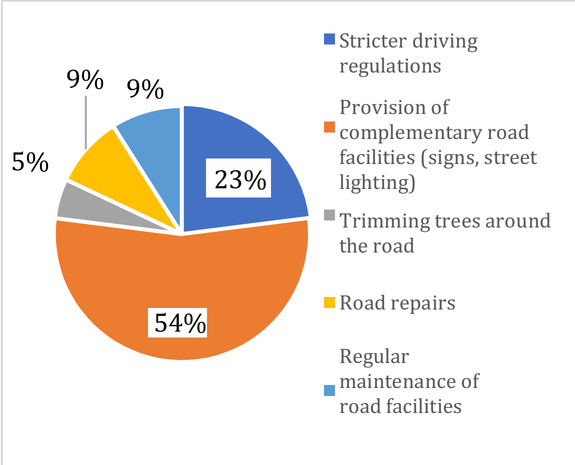


Figure 4. Diagram of Respondent Suggestions Regarding Traffic Accidents on Yogyakarta Barongan Road
Source: Reseach Data

Based on the respondent results, there is a need to provide complementary road facilities, such as signs and street lighting, which can reduce the potential for accidents. This was expressed by 54% of respondents.

Discussion

The research results show that the traffic characteristics on the Gading–Playen and Yogyakarta–Barongan Road Sections have quite significant differences. The Yogyakarta–Barongan road section shows a much higher traffic volume compared to the Gading–Playen road section, both on weekdays and holidays. This condition indicates that the Yogyakarta–Barongan Road functions as a movement corridor with higher traffic intensity; thus, the potential for traffic conflicts is also greater. This finding aligns with Sharma and Gupta (2020), who state that average daily traffic volume data are very important in transportation planning, traffic management, and road safety evaluation (Sharma & Choudhary, 2026). Furthermore, high vehicle volume on a road section can also increase exposure to accident risk if it is not balanced with adequate capacity and safety facilities (WHO, 2020).

Based on the results of converting traffic flow into passenger car units (PCU), it was found that the peak flow on Gading–Playen Road occurs on holidays at 16:00–17:00 UTC+7, reaching 658 pcu/h, whereas on Yogyakarta–Barongan Road the peak flow occurs on weekdays at 16:00–17:00 UTC+7, reaching 2,657 pcu/h. This difference indicates that mobility patterns on the two road sections are not the same. Gading–Playen Road tends to experience increased flow during periods associated with non routine mobility, while Yogyakarta–Barongan Road is more influenced by daily community activities. According to the Indonesian Road Capacity Guidelines, analysis of traffic flow during peak hours is an important basis for evaluating road performance and determining the level of service (Direktorat Jenderal Bina Marga, 2023). Therefore, the selection of peak hours in this study is appropriate to represent the most critical operational conditions.

From the vehicle speed perspective, the spot speed results show that the average speed on Gading–Playen Road tends to be higher compared to Yogyakarta–Barongan Road. On Gading–Playen Road, the average speed of motorcycles (MC) reached 50 km/h, light vehicles (LV) 48 km/h, and heavy vehicles (HV) 30 km/h, whereas on Yogyakarta–Barongan Road the corresponding speeds were 41 km/h, 35 km/h, and 29 km/h, respectively. Spot speed measurement is an important method in traffic studies because it describes instantaneous vehicle speed behavior at specific points, which subsequently affects traffic safety and evaluation of geometric road design (Elvik et al., 2009; Organization, 2023). This finding also aligns with (Schweppenhäuser et al., 2025), who affirm that spatiotemporal speed metrics are important in estimating traffic conditions on complex urban road sections. On the other hand, da Silva and Cavalcante (2025) show that vehicle speed is strongly influenced by road infrastructure characteristics, vehicle type, and traffic conditions. Thus, the speed differences between the two sections reflect the combined influence of traffic density and geometric road conditions.

Road capacity analysis shows that the capacity of the Gading–Playen Road section is 3,354 pcu/h, while the Yogyakarta–Barongan Road section is 3,444 pcu/h. Although the capacities are not significantly different, the degree of saturation (V/C ratio) shows quite different results, namely 0.196 for Gading–Playen Road and 0.771 for Yogyakarta–Barongan Road. According to the Directorate General of Highways (2023), the degree of saturation is the main indicator for assessing whether a road section is operating under stable conditions or approaching saturation. The low V/C ratio on Gading–Playen Road indicates that the section still has sufficient capacity for existing traffic flow. Conversely, the value of 0.771 on Yogyakarta–Barongan Road indicates that the section is approaching saturated conditions; therefore, the potential for traffic conflicts, vehicle deceleration, and accident risk becomes greater. In this context, a high degree of saturation reflects increased operational pressure on the road section.

The observed speed differential between the two road sections also has direct implications for accident risk. On the Gading–Playen section, where the V/C ratio is low (0.196), lower traffic density allows vehicles to travel at higher speeds (MC: 50 km/h; LV: 48 km/h). Higher operating speeds on roads with geometric deficiencies (e.g., substandard curve radii, narrow lanes, and inadequate superelevation) significantly increase crash severity and frequency, as kinetic energy in collisions increases with the square of speed (Elvik et al., 2009; Organization, 2023). Conversely, on the Yogyakarta–Barongan section, the higher V/C ratio (0.771) constrains vehicle speeds (MC: 41 km/h; LV: 35 km/h) but creates a high conflict environment due to frequent speed differentials between vehicle types and dense interactions. This inverse relationship between volume, speed, and accident risk underscores that both low density/high speed conditions and high density/high conflict conditions represent distinct but serious safety challenges (Geng et al., 2022).

When associated with accident data, the results show that Yogyakarta–Barongan Road has a higher risk level. The number of accidents on this section was recorded at 57 incidents in 2016–2017, decreased to 32 incidents in 2017–2018, then sharply increased to 114 incidents in 2018–2019. A z score value of +1.55 indicates that the accident rate in the last period is far above the mean, reflecting a significant spike in risk. Conversely, Gading–Playen Road recorded 12, 14, and 2 incidents across the same periods, with a z score of −1.13 in the last period, indicating below average conditions. The use of z scores is relevant because it shows how far a value deviates from its mean in standard deviation units (Montgomery & Runger, 2010; Martin & Bombaerts, 2026). This finding is reinforced by Zhang et al. (2022), who emphasize that accident frequency analysis must consider severity levels, time conditions, and traffic characteristics to identify high risk road sections. Similarly, Geng et al. (2022) state that statistical approaches are useful for predicting crash potential and identifying high risk locations. Meanwhile, Tang et al. (2021) add that accident analysis must consider field heterogeneity for more accurate interpretation (Zhang et al., 2025).

From the accident characteristics perspective, both road sections show relatively similar patterns. Accident victims are predominantly male, aged 16–25 years and 51–60 years, working as employees, with most incidents occurring between 06:00–12:00 UTC+7. The most involved vehicle type is the motorcycle, and the dominant causal factor is unsafe or undisciplined driving behavior. This finding aligns with the WHO (2020) report stating that motorcycle users are one of the most vulnerable road user groups, especially in developing countries. Syahriza (2019) also affirms that traffic accidents require special attention due to their significant health and socioeconomic impacts (Kalae et al., 2025). Harianto and Radam (2019) add that driver behavior is one of the main contributing factors to road accidents, particularly when combined with inadequate infrastructure (Kalae et al., 2025).

The geometric road conditions in this study also indicate a significant contribution to accident occurrence. On Gading–Playen Road, the lane width is only 5.1 meters with a 2/2 UD configuration, making it relatively narrow for a secondary collector road. In addition, small curve radii, misalignment between horizontal and vertical alignment, insufficient stopping sight distance, and substandard superelevation were identified. These conditions increase blind spots, skidding risk, and driving discomfort, especially at higher speeds. This aligns with Kronprasert et al. (2021), who found that curve radius and lane width are important variables in accident prediction models on rural two lane roads. Samsudin (2020) also explains that geometric and infrastructure factors strongly influence accident rates when design standards are not met (Sum et al., 2026).

On Yogyakarta–Barongan Road, although the lane width is larger (10.7 meters), geometric issues remain, including inconsistent horizontal–vertical alignment, potential reductions in stopping sight distance, and irregular superelevation. Furthermore, the relatively low average speed of light vehicles (around 35 km/h) reflects the influence of high traffic density and operational constraints. Pavement damage can further worsen safety conditions. Hashim et al. (2023) explain that pavement defects reduce operational performance and affect vehicle speed. Mei et al. (2022) emphasize the importance of routine pavement condition monitoring using technology based systems. Lepoglavec et al. (2023) add that accurate measurement of road geometry and longitudinal profiles is essential for comprehensive road condition assessment.

The survey results also reinforce the technical findings. On Gading–Playen Road, most respondents identified road repair as the primary measure to reduce accident risk, while on Yogyakarta–Barongan Road, respondents emphasized the need for road safety facilities such as signage and street lighting. Some also highlighted enforcement of traffic regulations, routine maintenance, and roadside vegetation management. These responses indicate that users have a clear perception of safety issues in the field. Mohammed and Ali (2021) explain that road user perception is an important input in safety evaluation because it reflects real world conditions. Thus, the survey results complement and strengthen the quantitative findings (Goel et al., 2024).

The discussion shows that accidents on both road sections are influenced by a combination of factors: traffic volume, vehicle speed, road capacity, geometric conditions, safety facilities, and driver behavior. Gading–Playen Road tends to be affected by geometric limitations and relatively higher speeds, while Yogyakarta–Barongan Road is more influenced by high traffic volume, near saturated conditions, and a significant increase in accident frequency. Therefore, mitigation efforts cannot rely on a single approach. Gading–Playen Road requires geometric improvements, enhanced superelevation, and pavement repair, while Yogyakarta–Barongan Road requires improved traffic management, additional safety facilities, routine maintenance, and stronger enforcement of driving discipline. This approach aligns with accident blackspot management principles that emphasize integrated technical, managerial, and educational interventions (Indonesia, 2021; Simanungkalit, 2022; Transportasi, 2004).

CONCLUSION

This study integrated the CUSUM and Z score statistical methods with the V/C ratio to perform a multidimensional traffic safety assessment of two accident prone road sections in the Special Region of Yogyakarta, Indonesia. The combined methodology provides a more comprehensive diagnostic framework than any single method alone, enabling both the detection of persistent black spot conditions and the quantification of capacity related accident risk.

The Gading–Playen Road section exhibits a low V/C ratio (0.196), indicating spare capacity, yet sustains elevated accident risk due to geometric deficiencies, including substandard lane width (5.1 m), small curve radii, inadequate superelevation, and misaligned horizontal–vertical transitions. On this section, lower traffic density enables higher vehicle speeds (MC average: 50 km/h; LV average: 48 km/h), amplifying crash severity given the geometric limitations. The CUSUM analysis confirms that this section did not trigger a persistent black spot alert over the study period (max $S_i = 3.34 < H = 5$), consistent with the observed accident decline in 2018–2019.

The Yogyakarta–Barongan Road section presents a qualitatively different risk profile. Its high V/C ratio (0.771) signals near saturated traffic conditions, and the CUSUM analysis triggered a definitive black spot alert in 2018–2019 ($S_3 = 31.33$, far exceeding $H = 5$). The Z score of +1.55 for the same period confirms that the accident frequency was a statistically significant anomaly rather than a marginal fluctuation. The convergence of high traffic density, geometric irregularities, and behavioral factors (predominantly undisciplined motorcycle use) makes this section the higher priority target for immediate infrastructure intervention.

From a policy perspective, the findings support a differentiated intervention strategy: geometric corrections (curve radius widening, superelevation standardization), and road surface rehabilitation for the Gading–Playen section; and traffic management reinforcement, installation of warning signs and lighting, and sustained law enforcement campaigns for the Yogyakarta–Barongan section. Both sections require priority attention to motorcycle safety, given the dominance of this vehicle class in the accident profile. Future research should extend the observation period beyond three years, incorporate injury severity data, and apply spatial clustering methods to more precisely delineate black spot zones within each section.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Universitas Esa Unggul for providing academic support, research facilities, and a collaborative environment that enabled the completion of this study. Appreciation is also extended to local authorities, traffic management personnel, and respondents who contributed data and insights regarding road safety on the Gading–Playen and Yogyakarta–Barongan road sections. Their assistance has been invaluable in ensuring the accuracy and comprehensiveness of this research.

AUTHOR CONTRIBUTION STATEMENT

Raafi Widyaputra Yulianyahya contributed to conceptualization, study design, and drafting the original manuscript. Ghefra Rizkan Gaffara contributed to data collection, formal analysis, and manuscript review. Ansadilla Niar Sitanggang contributed to methodology refinement, data interpretation, and validation of results. Irma Damayantie contributed to supervision, critical review, and editing of the manuscript. All authors have read and approved the final manuscript and take responsibility for the integrity and accuracy of the research.

REFERENCES

da Silva, A. R., & Cavalcante, R. N. (2025). Average speed dynamics on urban roads and highways: Influence of traffic infrastructure, vehicle and road characteristics on driving behavior. *Case Studies on Transport Policy*, 101591.

Direktorat Jenderal Bina Marga, K. P. R. I. (2023). Pedoman Kapasitas Jalan Indonesia. *Kementerian PUPR*.

Elvik, R., Høye, A., Vaa, T., & Sørensen, M. (2009). The Handbook Of Road Safety Measures. In *Elsevier*.

Geng, Z., Ji, X., Cao, R., Lu, M., & Qin, W. (2022). A Conflict Measures-Based Extreme Value Theory Approach To Predicting Truck Collisions And Identifying High-Risk Scenes On Two-Lane Rural Highways. *Sustainability*, *14(18)*.

Goel, R., Tiwari, G., Varghese, M., Bhalla, K., Agrawal, G., Saini, G., Jha, A., John, D., Saran, A., & White, H. (2024). Effectiveness Of Road Safety Interventions: An Evidence And Gap Map. *Campbell Systematic Reviews*, *20*(1), E1367.

Harianto, D., & Radam, I. (2019). Identification And Analysis On Causes Of Traffic Accident Factors In The Urban Roads In Paringin. *Global Journal Of Engineering Science Research*, *6(August)*.

Hashim, I. H., Badawy, R. M., & Heneash, U. (2023). Impact of pavement defects on traffic operational performance. *Sustainability*, *15*(10), 8293.

Indonesia, P. P. R. (2021). Peraturan Pemerintah Nomor 30 Tahun 2021 Tentang Penyelenggaraan Bidang Lalu Lintas Dan Angkutan Jalan. *Pemerintah Republik Indonesia*.

Jenderal, D., Marga, B., Direktorat, S., Bina, J., Direktur, P., Bina, J., Kepala, P., Kerja, S., & Bina, J. (2023). *No. 09/P/Bm/2023* (Issue 09).

Kalae, F. A., Kuswara, K. M., & Edyan, R. (2025). Analisis Kecelakaan Lalu Lintas Dikecamatan Teluk Mutiara Kota Kalabahi. *Jurnal Teknologi*, *19*(1), 24–33.

Kronprasert, N., Boontan, K., & Kanha, P. (2021). Crash Prediction Models For Horizontal Curve Segments On Two-Lane Rural Roads In Thailand. *Sustainability*, *13(16)*, 1–18.

Lepoglavec, K., Šušnjar, M., Pandur, Z., Bačić, M., Kopseak, H., & Nevečerel, H. (2023). Correct Calculation Of The Existing Longitudinal Profile Of A Forest/Skid Road Using Gnss And A

UAV Device. *Forests*, *14(4)*.

Martin, D. A., & Bombaerts, G. (2026). Mapping Engineering Students' Conceptions Of Responsibility In Challenge-Based Learning: The Agency Gap. *Journal Of Engineering Education*, *115*(2), E70057.

Mei, A., Zampetti, E., P, D. M., Fontinovo, G., Papa, P., & D'andrea, A. (2022). Roads—Rover For Bituminous Pavement Distress Survey: An Unmanned Ground Vehicle (Ugv) Prototype For Pavement Distress Evaluation. *Sensors*, *22(9)*.

Mekonnen, A. A., & Sipos, T. (2022). Crash Prediction Models And Methodological Issues. *Periodica Polytechnica Transportation Engineering*, *50*(3), 267–272.

Mitra, S., & Washington, S. (2016). On The Nature Of Over-Dispersion In Motor Vehicle Crash Prediction Models. *Accident Analysis & Prevention*, *91*, 1–15. https://doi.org/10.1016/J.Aap.2016.02.020

Mohammed, S., & Ali, H. (2021). Road Safety And Public Perception: A Study Of User Feedback. *Journal Of Safety Research*, *75*.

Montgomery, D. C., & Runger, G. C. (2010). *Applied statistics and probability for engineers*. John Wiley & Sons.

Organization, W. H. (2020). Global Status Report On Road Safety 2020. *WHO*.

Organization, W. H. (2023). *Pedestrian Safety: A Road Safety Manual For Decision-Makers And Practitioners*. World Health Organization.

Samsudin, I. (2020). Analisa Faktor Penyebab Kecelakaan Pada Ruas Jalan Ir. H. Alala Kota Kendari Ditinjau Dari Prasarana Dan Geometrik Jalan. *Jurnal Penelitian Transportasi Darat*, *21(1)*, 59–66.

Schweppenhäuser, M., Schrab, K., Protzmann, R., & Radusch, I. (2025). Evaluating Spatiotemporal Speed Metrics For Traffic State Estimation On Complex Urban Roads. *Simulation*, *101(1)*, 45–61. https://doi.org/10.1177/00375497241308890

Sharma, A., & Gupta, R. (2020). Traffic Volume Studies And Their Importance In Transportation Planning. *International Journal Of Traffic And Transportation Engineering*, *9(3)*, 65–72. https://doi.org/10.5923/J.Ijtte.20200903.01

Sharma, S., & Choudhary, P. (2026). Which Factors Compromise Safety On Mountainous Roads: A Systematic Review. *Journal Of Traffic And Transportation Engineering (English Edition)*.

Simanungkalit, R. R. (2022). *Perlindungan Hukum Terhadap Hak Pengguna Jalan Dalam Peraturan Pemerintah Nomor 30 Tahun 2021 Tentang Penyelenggaraan Bidang Lalu Lintas Dan Angkutan Jalan Perspektif Maqasid Asy-Syari 'Ah*. UIN Sunan Kalijaga Yogyakarta.

Sum, S., Wisutwattanasak, P., Champahom, T., Jomnonkwao, S., & Ratanavaraha, V. (2026). Predicting Motorcycle Crash Severity On Thailand's Curved Roadways: A Deep Learning Approach. *Iatss Research*, *50*(1), 786–800.

Syahriza, M. (2019). Kecelakaan Lalulintas: Perlukah Mendapatkan Perhatian Khusus? *Averrous: Jurnal Kedokteran Dan Kesehatan Malikussaleh*, *5(2)*, 89.

Tang, F., Fu, X., Cai, M., Lu, Y., & Zhong, S. (2021). Investigation Of The Factors Influencing The Crash Frequency In Expressway Tunnels: Considering Excess Zero Observations And Unobserved Heterogeneity. *IEEE Access*, *9*, 58549–58565.

Transportasi, P. L. P. (2004). Penanganan Lokasi Rawan Kecelakaan Lalu Lintas. *Pusat Litbang Prasarana Transportasi*.

Zhang, L., Huang, Z., Zhu, L., & Yang, S. (2025). Investigating Influential Factors Through Crash Frequency Models Considering Excess Zeros And Heterogeneity: New Insights Into Mountain Freeway Safety. *Plos One*, *20*(4), E0320135.

Zhang, P., Wang, C., Chen, F., Cui, S., Cheng, J., & Bo, W. (2022). A Random-Parameter Negative Binomial Model For Assessing Freeway Crash Frequency By Injury Severity: Daytime Versus Nighttime. *Sustainability*, *14(15)*.