

## STUDY OF GEOMETRIC DESIGN INTERACTION, SPEED BEHAVIOR, AND ACCIDENT POTENTIAL ON URBAN ROAD SEGMENTS

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### ABSTRACT

Road safety on curved segments that directly interact with at-grade intersections in urban areas remains a serious challenge in Indonesia. This study aims to analyze the relationship between road geometric characteristics (curve radius, superelevation, lane width, and stopping sight distance) on vehicle speed and traffic conflict potential, while formulating mitigation strategies at three curve locations in Kediri City intersections. A quantitative descriptive-analytic approach was applied through geometric measurement according to PDGJ 2021, spot speed surveys on 2,455 vehicle samples, and conflict observation using the Swedish Traffic Conflict Technique on 522 conflict events during peak hours. Results show stopping sight distance as the most dominant geometric variable on speed ( $r = +0.590$ ;  $R^2 = 0.997$ ), followed by curve radius ( $r = -0.436$ ) and superelevation ( $r = +0.404$ ). Geometric correlation with serious conflict frequency is weak ( $r = -0.191$  to  $+0.224$ ), while 94.6% of 522 events are serious conflicts. Merging conflicts dominate on Ahmad Dahlan Road, whereas stopping conflicts occur exclusively on Imam Bonjol Road due to stopping sight distance deficiency. Mitigation strategies are formulated based on seven hierarchical risk factors encompassing infrastructure improvement, traffic management, and integrated road user behavior interventions.

Keywords: road geometry; road safety; traffic conflicts; urban curve; vehicle speed

### INTRODUCTION

Road safety remains a major challenge in Indonesia. Data from the Indonesian National Police Traffic Corps (Pusiknas) in 2024 recorded 149,882 traffic accident incidents resulting in 16,322 fatalities, and 16% of them occurred on road sections involving curves and intersections. This condition reflects a systemic failure in integrating safety aspects into road geometric planning, particularly on segments with complex characteristics (Valdiansyah et al., 2024). This problem becomes increasingly critical in medium-sized cities like Kediri City, where the annual growth rate of motor vehicle volume of 7.5% also impacts accident frequency (BPS Kota Kediri, 2025). Analysis of accident data from the Kediri City Police Resort for the 2020-2024 period shows incidents concentrated on horizontal alignment segments that directly interact with intersections.

This configuration forces drivers to simultaneously adjust speed to the road curvature and face conflict streams from the minor intersection leg, thereby producing high-speed variations, sudden maneuvers, and limited reaction time that potentially lead to accidents. Various studies have proven the relationship between geometric characteristics, vehicle speed, and accident potential. Studies by Li et al. (2025) and Tottadi dan Mehar (2024) confirm that curve radius significantly affects operational speed. Cahayani et al. (2020) proved that up to 99.3% of speed variation can be explained by radius and grade through a non-linear model. Ramezani-Khansari, Nejad, et al., (2024) added that superelevation and road slope also play important roles. In terms of traffic conflicts, Ospina-Mateus et al. (2023) affirmed that motorcycles experience more severe conflicts compared to other vehicles at unsignalized intersections, a condition highly relevant to the dominance of motorcycles in Indonesia.

The novelty of this research lies in investigating the interaction between curve geometric design and traffic conflict dynamics on segments that are simultaneously curves and located in intersection areas, a configuration that has not been extensively explored in previous literature. This study aims to analyze the relationship between geometric characteristics and vehicle speed, analyze the relationship between geometric characteristics and traffic conflict potential, and formulate road safety mitigation strategies based on empirical findings. The results are expected to contribute to road safety policies in Kediri City, while also supporting the Sustainable Development Goals targets in reducing traffic accident fatalities.

## **METHOD**

### **Research Design and Study Location**

This study uses a quantitative descriptive-analytic approach conducted at three curves in intersection areas of Kediri City. Two curves are located on Ahmad Dahlan Road, which is a national road type 2/2 UD based on the Minister of Public Works and Housing Decree Number 1688/KPTS/M/2022, and one curve on Imam Bonjol Road, which is a city road type 2/1 UD based on the East Java Governor Decree Number 188/207/KPTS/013/2023. All three curves are of the *Spiral-Circle-Spiral* type with a design speed of 50 km/h. Location selection was based on accident data from the Kediri City Police Resort for the 2020-2024 period indicating incident concentration on curved segments adjacent to intersections, as well as direct observation results identifying high-speed behavior and difficulties for vehicles from the minor leg in estimating safe gaps.

The independent variables of this research include curve radius ( $X_1$ ), superelevation ( $X_2$ ), lane width ( $X_3$ ), and stopping sight distance ( $X_4$ ) referring to PDGJ 2021. The dependent variables consist of average vehicle speed ( $Y_1$ ) and serious traffic conflict frequency ( $Y_2$ ). The research framework is built on the premise that road safety is a function of the interaction between three systems: geometric infrastructure, speed behavior, and traffic conflict dynamics. The safe road approach from Mulyono (2022) which includes Self-Regulating, Self-Explaining, Self-Enforcing, and Self-Forgiving Road becomes the conceptual basis for formulating mitigation strategies.

### **Data Collection**

Primary data were collected through four integrated field survey methods. First, road geometric surveys using a roll meter, walking measure, and clinometer application to measure curve radius, superelevation, lane width, shoulder width, normal cross slope, and stopping sight distance. Each parameter was measured at least three times per point and averaged to minimize reading errors. Second, traffic volume surveys were conducted during three time periods, namely morning (06.00-09.00 WIB), afternoon (11.00-14.00 WIB), and evening (15.30-18.30 WIB), with 15-minute counting intervals. Vehicles were categorized into Motorcycles (SM), Passenger Cars (MP), Medium Vehicles (KS), and Non-Motorized Vehicles (KTB). The purpose of this survey was to identify peak hours as the reference time for speed and traffic conflict surveys.

Third, vehicle speed measurements were carried out using the spot speed method under free-flow conditions at three measurement positions in each segment, namely before the curve, at the curve, and after passing the curve (Venasius et al., 2022). The number of samples was determined using the Slovin formula with a 5% margin of error from the vehicle population during peak hours, resulting in a total of 2,455 speed data points. Fourth, traffic conflict observations adapted the Swedish Traffic Conflict Technique (STCT) developed by Hyden

(1987). Observations were conducted during peak hours (06.30-07.30 WIB) using video recordings from a viewpoint that covered the entire potential conflict area.

For each conflict event, two parameters were measured: vehicle speed when starting to evade and the vehicle's distance to the imaginary collision point. The Time to Accident (TA) value was determined through bilinear interpolation on Hyden's (1987) TA Table to classify each conflict as serious or non-serious.

### Data Analysis and Framework

Data analysis was performed using IBM SPSS Statistics 2023 through three stages. First, descriptive statistics of all variables to provide a comprehensive overview of field condition (Martias, 2021). Second, classical assumption tests including the Shapiro-Wilk normality test because the data were less than 50 samples and the Glejser heteroscedasticity test to validate the feasibility of the correlation model (Muliana et al., 2025; Puput & Sucipto, 2024). Third, Pearson correlation analysis and coefficient of determination ( $R^2$ ) to measure the direction, strength, and proportion of variation that can be explained by each geometric parameter on the dependent variable (Al'Adilah et al., 2021). Interpretation of correlation coefficient categories refers to the five levels presented in table 1.

Tabel 1.  
 Correlation Coefficient Interval

Coefficient Interval	Correlation Coefficient
0,00-0,199	Very Low
0,20-0,399	Low
0,40-0,599	Moderate
0,69-0,799	High
0,80-1,000	Very High

The research framework is visualized as a three-layer system presented in Figure 1. The first layer is input in the form of geometric characteristics (radius, superelevation, SSD) that directly shape the physical condition of the curve. The second layer is a process in the form of interaction between geometry and driver behavior that produces operational speed patterns and traffic conflict dynamics in intersection areas. The third layer is output in the form of risk factor identification and formulation of mitigation strategies analyzed through the SWOT approach referring to safe road principles. The relationship between these three layers forms a comprehensive analytical basis to answer the three research problem formulations.

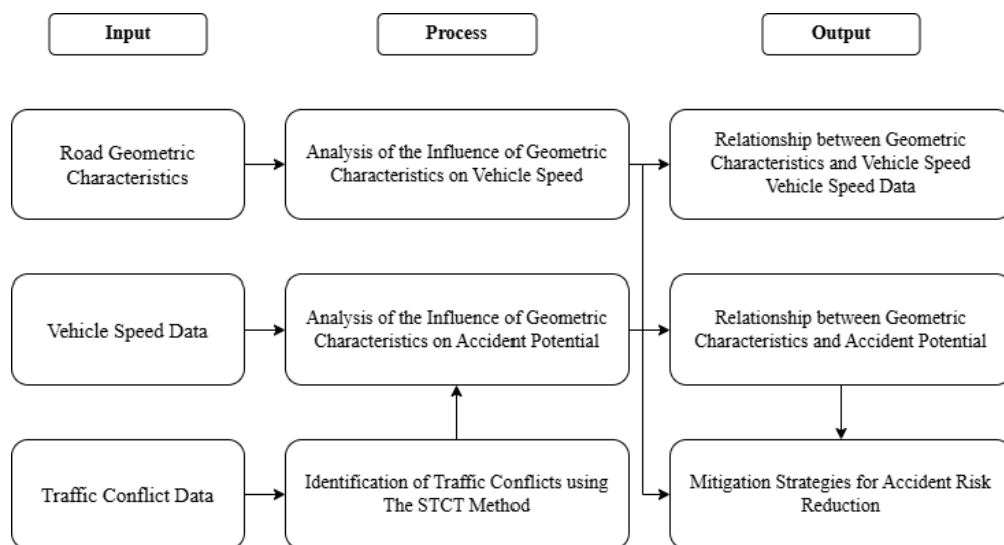


Figure 1. Research Framework

## RESULT AND DISCUSSION

### Geometric Conditions, Traffic Volume, and Vehicle Composition

Field geometric measurements produced the characteristics of the three curves as presented in Table 2. The main difference between the three curves lies in the combination of radius, superelevation, and stopping sight distance which directly affect driving behavior.

Table 2.

Existing Road Geometric Characteristics at Curve Locations					
No	Geometric Parameter	Unit	Ahmad Dahlan Road 1	Ahmad Dahlan Road 2	Imam Bonjol Road
1	Curve Angle ( $\beta$ )	$^{\circ}$	32	39	32
2	Curve Radius (R)	m	85,587	82,020	98,425
3	Superelevation (e)	%	7	8	4
4	Lane Width	m	5	5	5
5	Shoulder Width	m	1,5	2,0	2,0
6	Normal Cross Slope	%	2	2	2
7	Stopping Sight Distance (JPH)	m	92	93,5	47
8	Curve Type	-	<i>Spiral-Circle-Spiral</i>	<i>Spiral-Circle-Spiral</i>	<i>Spiral-Circle-Spiral</i>

Ahmad Dahlan Road 2 has the smallest radius of 82.020 m with the highest superelevation of 8%, which is the maximum limit allowed by PDGJ 2021. Imam Bonjol Road recorded the most critical Stopping Sight Distance deficiency, which is only 47 m or 27.7% below the minimum value of 65 m, so drivers do not have an adequate safe distance for emergency stopping. The uniform lane width of 5 m at all three locations meets and even exceeds the PDGJ 2021 minimum standard of 3.5 m for urban roads with a design speed of 50 km/h. The traffic volume survey identified consistent peak hours in the morning session at all three locations, coinciding with the flow of work and school departures. The recapitulation of the highest peak hours is presented in Table 2.

Table 2.

Recapitulation of the Highest Peak Hours at All Curve Locations				
Location	Peak Hour	Vol Direct. 1	Vol Direct. 2	Total (veh./hour)
Curve 1 Ahmad Dahlan Road	06.30-07.30	2.265 (North)	2.996 (South)	5.261
Curve 2 Ahmad Dahlan Road	06.30-07.30	2.094 (North)	2.420 (South)	4.514
Curve 3 Imam Bonjol Road	06.30-07.30	2.229 (East)	-	2.229

Ahmad Dahlan Road 1 recorded the highest peak hour volume of 5,261 vehicles per hour from two directions, followed by Ahmad Dahlan Road 2 with 4,514 vehicles per hour. Imam Bonjol Road as a one-way road recorded 2,229 vehicles per hour. The 15-minute volume fluctuations at the three locations, which showed sharp spikes in the 06.45-07.00 WIB interval, are presented in Figures 2 to 4.

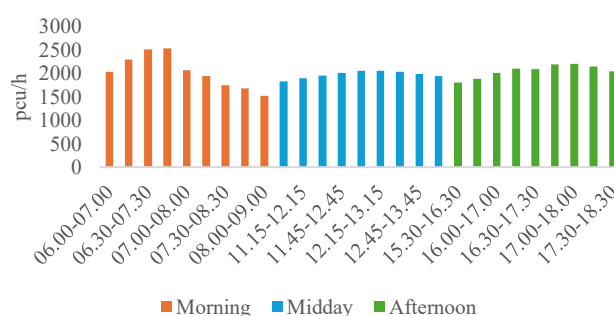


Figure 2. Traffic Volume Fluctuations at Curve 1 of Ahmad Dahlan Road

In the morning, a traffic surge occurred at 06:45–07:00, with traffic volumes reaching 846 vehicles in the northbound direction and 1,144 vehicles in the southbound direction. Motorcycles dominated the traffic composition, accounting for 86.9% of the total vehicles, followed by passenger cars at 12.6%. The midday session was more evenly distributed, with the peak occurring at 12:00–12:30. The afternoon session showed two peak periods, namely at 16:15–17:00 and 17:30–18:00, with higher traffic volume in the southbound direction toward residential areas.

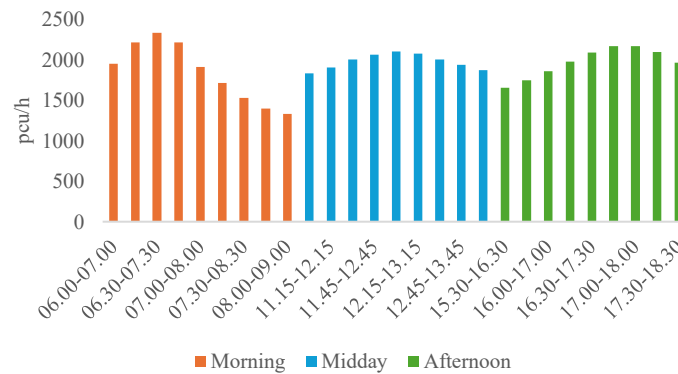


Figure 3. Traffic Volume Fluctuations at Curve 2 of Ahmad Dahlan Road

The fluctuation pattern of traffic volume at Curve 2 on Ahmad Dahlan Road showed a trend similar to that of Curve 1. In the morning, the highest peak occurred during the 06:45–07:00 interval, with traffic volumes reaching 660 vehicles in the northbound direction and 757 vehicles in the southbound direction. These figures were lower than those at Curve 1 due to differences in position along the same road segment. During midday, traffic volume tended to be stable and lower compared to the morning and afternoon periods. Motorcycles continued to dominate the traffic composition at 85.3%, followed by passenger cars at 13.8%. In the afternoon, traffic volume gradually increased, peaking between 17:15 and 17:45, with higher traffic volume in the southbound direction than in the northbound direction, confirming the return-flow pattern toward residential areas.

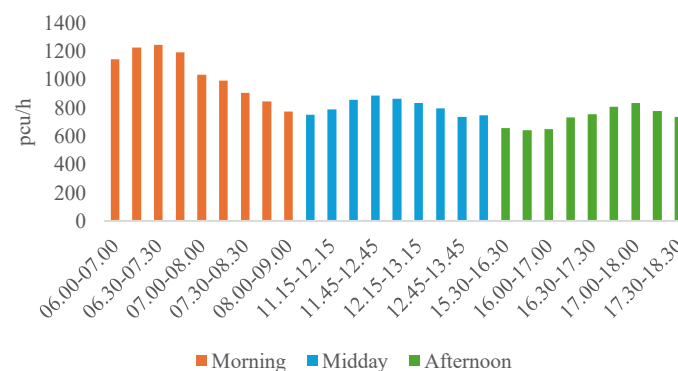


Figure 4. Traffic Volume Fluctuations at Curve 3 of Imam Bonjol Road

Curve 3 on Imam Bonjol Road only accommodates one-way traffic flowing eastbound. The highest morning traffic volume was recorded during the 06:45–07:00 interval, reaching 713 vehicles, after which the volume gradually decreased. Motorcycles dominated the traffic composition with a proportion of 74.4%, while passenger cars accounted for 24.2%. During the midday session, traffic volume was more evenly distributed, with the peak occurring at 12:15–12:30, and the proportion of passenger cars was higher than in the morning period. In the afternoon session, traffic volume increased significantly between 17:00 and 17:45, with the

highest peak recorded at 17:30–17:45, approaching the morning traffic volume. This indicates that the route serves as one of the main corridors for evening return traffic flow. Motorcycles dominate the composition at all three locations with proportions of 86.9% on Ahmad Dahlan Road 1, 85.3% on Ahmad Dahlan Road 2, and 74.4% on Imam Bonjol Road. This dominance is critical for safety because motorcycles are the most vulnerable user group to conflicts at unsignalized intersections (Ospina-Mateus et al., 2023). High volume with a dominant motorcycle composition creates operational conditions that inherently increase the potential for dangerous interactions.

### Analysis of the relationship between geometric characteristics and vehicle speed

Spot speed measurements of 2,455 vehicle samples revealed significantly varying speed patterns between locations. The largest average speed reduction occurred on Ahmad Dahlan Road 2 with an average of 7.54 km/h or 17.1%, directly related to the most critical geometric combination, namely the smallest radius of 82.02 m, the largest curve angle  $\beta = 39^\circ$ , and the highest superelevation of 8%. This finding aligns with Tottadi and Mehar (2024) who affirmed that larger curve angles correlate with more significant operational speed reductions. Table 3 presents the average speeds at three measurement positions along with the magnitude of their reduction.

Table 3.  
Recapitulation of Average Vehicle Speeds at All Research Locations

Location-Direction	V Before (km/h)	V At (km/h)	V After (km/h)	Reduction (km/h)	Reduction (%)
Jl. Ahmad Dahlan 1-Utara	44,31	40,01	43,51	4,30	9,7%
Jl. Ahmad Dahlan 1-Selatan	43,11	39,47	43,25	3,64	8,4%
Rata-rata AD 1	43,71	39,74	43,38	3,97	9,1%
Jl. Ahmad Dahlan 2-Utara	46,11	37,61	41,31	8,50	18,4%
Jl. Ahmad Dahlan 2-Selatan	41,87	35,30	42,79	6,57	15,7%
Rata-rata AD 2	43,99	36,45	42,05	7,54	17,1%
Jl. Imam Bonjol-ke Timur	41,48	38,71	41,56	2,77	6,7%

The condition on Imam Bonjol Road is actually cause for concern. A speed reduction of only 2.77 km/h or 6.7% on a curve that has an SSD of only 47 m indicates that drivers do not adjust their speed proportionally to the existing risk. More worryingly, some drivers recorded post-curve acceleration of up to 81.45 km/h, a very dangerous behavior because the area directly borders an intersection. All average speed values in the curve area ranging from 39.99-42.61 km/h are below the design speed of 50 km/h, but V85 values range from 44.92-50.72 km/h and maximum values reach 62.69 km/h, exceeding the design speed in several events. The results of the Pearson correlation analysis between geometric parameters and vehicle speed are presented in Table 4.

Table 4.  
Correlation Test Results and Coefficient of Determination for Geometric Relationship with Speed

Geometric Parameter	r Pearson	Category	R <sup>2</sup>	Direction of Relationship
Curve Radius ( $X_1$ )	-0,436	Moderate	78,6%	Negative
Superelevation ( $X_2$ )	+0,404	Moderate	70,3%	Positive
Stopping Sight Distance ( $X_3$ )	+0,590	Moderate	99,7%	Positive

Stopping sight distance is the most dominant geometric variable on speed with  $r = +0.590$  and  $R^2 = 0.997$ . The  $R^2$  value approaching 1.0 reflects that the SSD deficiency at Curve 3 of Imam Bonjol Road has a dominant influence in shaping operational speed patterns. Curve radius shows a negative correlation ( $r = -0.436$ ;  $R^2 = 0.786$ ), confirming the natural speed adaptation mechanism of drivers on small-radius curves as stated by Li et al. (2025). Superelevation shows a positive correlation ( $r = +0.404$ ;  $R^2 = 0.703$ ), reflecting the inherent design relationship that high-superelevation curves are designed for higher speeds. However, the fact that Curve 2 with 8% superelevation and a radius of 82.02 m actually recorded the largest speed reduction of 17.1% confirms that superelevation cannot work optimally without an adequate radius (Ramezani-Khansari, Moghadas Nejad, et al., 2024).

### Analysis of the relationship between geometric characteristics and conflict potential

STCT observations during peak hours identified a total of 522 conflict events at the three locations. Details of conflict types and severity levels are presented in table 5.

Table 5.

Recapitulation of Traffic Conflict Types and Severity Levels Location

Location	<i>Crossing</i>	<i>Diverging</i>	<i>Merging</i>	<i>Stopping</i>	Serious	Non-Serious	Total
Ahmad Dahlan 1	20 (12,7%)	39 (24,8%)	98 (62,4%)	0 (0,0%)	147	10	157
Ahmad Dahlan 2	43 (22,9%)	72 (38,3%)	73 (38,8%)	0 (0,0%)	182	6	188
Imam Bonjol	22 (12,4%)	60 (33,9%)	30 (16,9%)	65 (36,7%)	165	12	177
Total	85 (16,3%)	171 (32,8%)	201 (38,5%)	65 (12,5%)	494	28	522

Of the 522 conflict events, 494 or 94.6% were serious conflicts with Time to Accident (TA) values above Hyden's (1987) line. Merging conflict types dominate on Ahmad Dahlan Road 1 with 62.4% and Ahmad Dahlan Road 2 with 38.8%, reflecting the high intensity of vehicles from the minor leg merging into the high-volume main lane right in the curve area. Stopping conflicts occurred exclusively on Imam Bonjol Road with 65 events per hour or 36.7% of the total conflicts at that location, a direct manifestation of SSD deficiency that limits drivers' early detection capability. Ahmad Dahlan Road 2 recorded the lowest average TA of 0.62 seconds and the highest proportion of serious conflicts at 96.8%, consistent with its most critical geometric characteristics.

Motorcycles were involved in 88.3-96.8% of all conflict events at the three locations. The highest involvement was recorded on Ahmad Dahlan Road 1 with 96.8% (all conflicts involved motorcycle-motorcycle and passenger car-motorcycle interactions), consistent with motorcycle dominance of more than 87% in the traffic composition. This finding aligns with Ospina-Mateus et al. (2023) who proved that motorcycles experience more severe conflicts compared to other vehicles at unsignalized intersections. The bivariate correlation analysis between geometric parameters and serious conflict frequency produced values as presented in Table 6.

Table 6.

Correlation Test Results and Coefficient of Determination for Geometric Relationship with Conflict Potential

Geometric Parameter	r Pearson	Category	R <sup>2</sup>	Direction of Relationship
Curve Radius ( $X_1$ )	-0,191	Very Low	0,786	Negative
Superelevation ( $X_2$ )	+0,224	Low	0,703	Positive
Stopping Sight Distance ( $X_3$ )	+0,012	Very Low	0,997	Positive

The bivariate correlation between geometric parameters and conflict potential is weak overall. Superelevation produced the highest value with  $r = +0.224$  in the "Low" category, followed by curve radius with  $r = -0.191$  in the "Very Low" category, and stopping sight distance with  $r =$

+0.012 in the "Very Low" category. The weakness of this correlation reflects that the occurrence of traffic conflicts at intersection curves is a multidimensional phenomenon simultaneously influenced by geometric factors, traffic volume, driver behavior, and the characteristics of the intersection itself. This finding aligns with Ospina-Mateus et al. (2023) who affirmed that driver behavior, especially speed decisions and gap acceptance, is a more dominant contributor to conflict risk, not geometry alone. Nevertheless, Ahmad Dahlan Road 2 with the smallest radius and highest superelevation recorded the most serious conflicts, providing consistent qualitative evidence that critical geometric combinations increase operational risk.

The results of this study prove that stopping sight distance (SSD) is the most dominant geometric variable affecting vehicle speed on urban intersection curves ( $r = +0.590$ ;  $R^2 = 0.997$ ), followed by curve radius ( $r = -0.436$ ) and superelevation ( $r = +0.404$ ). These findings reinforce the theory of vehicle mechanics on horizontal alignment and are consistent with studies by Li et al. (2025) and Tottadi & Mehar (2024), which state that curve radius significantly influences operating speed. The negative correlation of radius to speed confirms the natural adaptation mechanism of drivers on small-radius curves, while the positive correlation of superelevation reflects an inherent design relationship that cannot work optimally without adequate radius (Ramezani-Khansari, Moghadas Nejad, et al., 2024).

On the other hand, the bivariate correlation between geometric parameters and serious conflict frequency is weak ( $r = -0.191$  to  $+0.224$ ), indicating that conflict potential at curve-intersection configurations is a multidimensional phenomenon. This finding aligns with Ospina-Mateus et al. (2023), who assert that driver behavior, especially speed decisions and gap acceptance, plays a more dominant role than geometry alone. Merging conflicts dominate on Ahmad Dahlan Road (38.8%-62.4%), reflecting the failure of integration between curve geometry and flow management from minor intersection legs, while stopping conflicts occur exclusively on Imam Bonjol Road (65 events/hour) as a direct manifestation of SSD deficiency that limits drivers' early detection capability.

This study has limitations regarding the scope of locations, which only includes three sites in Kediri City, and conflict observations limited to the morning peak hour, thus the results cannot be directly generalized to all urban intersection curves in Indonesia. Furthermore, the quantitative descriptive-analytic approach with bivariate correlation analysis has not been able to reveal causal relationships in depth nor capture the simultaneous influence of geometric parameters or driver behavior variables. Nevertheless, these findings make an important contribution to the development of road transportation system engineering knowledge, especially in the context of medium-sized cities with motorcycle dominance.

This study enriches the safe road framework of Mulyono (2022) with empirical evidence that safety at curve-intersection configurations requires an integrated systemic approach encompassing physical infrastructure improvement, traffic management, as well as road user behavior interventions simultaneously, not merely single-dimensional geometric interventions. Further research with a broader scope of locations and multivariate analysis is needed to build a more comprehensive safety prediction model through the integration of driver behavior variables, traffic composition, pavement surface conditions (Oktopianto et al., 2025, 2026), road skid resistance (Phahlevi et al., 2026), and road environmental characteristics that potentially affect conflict levels and accident risks on urban roads.

## CONCLUSION

Based on the analysis of 2,455 speed data points and 522 STCT conflict events at three intersection curves in Kediri City, this study concludes two main points. First, geometric characteristics have a significant relationship with vehicle speed, where stopping sight distance is the most dominant variable ( $r = +0.590$ ;  $R^2 = 0.997$ ), followed by curve radius ( $r = -0.436$ ;  $R^2 = 0.786$ ) and superelevation ( $r = +0.404$ ;  $R^2 = 0.703$ ). Second, the correlation between geometric parameters and serious conflict frequency is weak ( $r = -0.191$  to  $+0.224$ ), with 94.6% of 522 events being serious conflicts, indicating that conflict potential is multidimensional. Merging conflicts dominate Ahmad Dahlan Road (38.8%-62.4%) while stopping conflicts occur exclusively on Imam Bonjol Road due to stopping sight distance deficiency. Motorcycles are involved in 88.3%-96.8% of all serious conflicts.

Accordingly, a sustainable reduction in accident risk can be achieved through the integration of physical infrastructure improvements, adaptive traffic management practices, and evidence-based behavioral and institutional interventions, creating a holistic road safety framework capable of addressing both operational and systemic risk factors. This study enriches the safe road framework with empirical evidence from the context of medium-sized cities dominated by motorcycles, while also serving as a foundation for the development of multivariate safety prediction models at urban curve-intersection configurations.

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