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Road Attributes and Traffic Characteristics Effects on Motorcycle Safety

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ABSTRACT

In Indonesia, motorcycles dominate the transport landscape, with over 125 million registered motorcycles as of 2025. The country faces a significant road safety challenge, recording over 31,000 road traffic deaths annually, with motorcycles involved in many fatal crashes. Infrastructure-based interventions have shown promise in mitigating these risks. However, the implementation remains uneven, and effectiveness varies by region. Therefore, a systematic assessment of the influence of road conditions on motorcycle safety and evaluating the impact of infrastructure-based countermeasures in reducing crash risk and injury severity is needed. This study aims to systematically assess the road safety risk for motorcyclists in campus areas, with a specific focus on the role of local road attributes and traffic characteristics to propose suitable infrastructure-based countermeasures in reducing crash risk and injury severity. The method used is a road assessment tool developed by the International Road Assessment Programme (iRAP). The results show that The road attributes that play the most crucial role in determining the SRS value for a motorcycle on a road segment in the UGM campus area are those that contribute to accident likelihood: curvature, median transversability, and operating speed. Although previous research has shown operating speed to be a mediating variable rather than a direct factor in accident occurrence, it is essential to consider the factors that contribute to accidents. For intersections, the road attributes that significantly determine the level of safety are those that influence the likelihood and severity. The road attributes that influence likelihood are curvature, intersection quality, channelization, and property access points. The road attributes that influence severity are roadside severity – distance, paved shoulder width, and property access points.

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1. INTRODUCTION

Road safety remains a pressing global issue, with traffic crashes claiming approximately 1.19 million lives annually [1]. Vulnerable road users—motorcyclists, pedestrians, and cyclists—make up more than half of these fatalities, with motorcyclists alone accounting for 28% of global road deaths [2]. The risk is especially acute in low- and middle-income countries, which bear 92% of the world's road fatalities despite having only 60% of the vehicles [1].

In Indonesia, motorcycles dominate the transport landscape, with over 125 million registered motorcycles as of 2025. The country faces a significant road safety challenge, recording over 31,000 road traffic deaths annually, with motorcycles involved in many fatal crashes. Urban congestion, limited public transport, and affordability make motorcycles the preferred mode of travel, but also expose riders to heightened risks [3].

While behavioural factors such as speeding, helmet non-use, and distracted riding contribute to crash risk, road conditions are a critical and often under-addressed determinant of motorcycle safety [4] [5]. Poor pavement quality, potholes, loose gravel, inadequate drainage, and a lack of signage or lighting increase the likelihood of single-vehicle crashes and collisions with other road users [4][6]. Motorcyclists are particularly vulnerable to surface irregularities due to their vehicle dynamics and lack of protective enclosure [4][6].

Infrastructure-based interventions have shown promise in mitigating these risks. Key measures include dedicated motorcycle lanes to separate riders from faster, heavier vehicles [7], improved pavement quality and regular maintenance to eliminate surface hazards, motorcycle-friendly roadside barriers that reduce injury severity in run-off-road crashes, intersection redesigns with advanced stop lines and protected turn phases, reflective road markings and hazard signage to enhance visibility [8]. Despite these efforts, implementation remains uneven, and effectiveness varies by region. Therefore, a systematic assessment of the influence of road conditions on motorcycle safety and evaluating the impact of infrastructure-based countermeasures in reducing crash risk and injury severity is needed.

Furthermore, road safety research has focused on arterial and collector roads due to their higher traffic volumes and speeds. These roads are often prioritized in infrastructure planning and enforcement strategies. However, recent studies and crash data analyses reveal that local roads—including those within and surrounding campus areas—exhibit accident rates that are comparable to, and in some cases exceed, those of collector and arterial roads [9][4][5][6]. This trend is particularly concerning given the perception that local roads are inherently safer due to lower speed limits and reduced traffic complexity [[10].

In campus environments, roads are mostly local and frequently shared by motorcyclists, pedestrians, cyclists, and service vehicles, resulting in a complex and dynamic traffic mix. The massive use of motorcycles is also found among students and staff in university environments, where affordability and accessibility make them the preferred mode of travel. The lack of dedicated motorcycle lanes, poor visibility at intersections, inadequate signage, and inconsistent pavement quality contribute to elevated crash risks. Moreover, behavioral factors such as distracted riding, helmet non-use, and informal parking practices exacerbate safety challenges in these settings [11].

Several universities have implemented localized safety interventions, including speed calming measures, improved lighting, and awareness campaigns. As mentioned in the earlier paragraph, the effectiveness of these efforts remains uneven, and comprehensive data-driven approaches are still limited. This condition also occurs at Universitas Gadjah Mada, where motorcycle crashes remain high, given the number of motorcyclists in this campus area [12]. Given the high exposure of motorcyclists in campus areas and the comparable crash rates on local roads, there is an urgent need to reevaluate infrastructure and policy priorities to better address safety risks in these environments. This study aims to investigate the road safety risk for motorcyclists in campus areas, specifically the Universitas Gadjah Mada campus area, with a specific focus on the role of local road conditions and traffic dynamics.

The International Road Assessment Programme (iRAP) is a tool that can be used to assess road safety risk. The iRAP evaluates road safety by assessing infrastructure attributes that impact crash likelihood and severity, assigning Star Ratings from 1-5 stars based on built-in safety features relative to traffic speeds [13]The iRAP model calculates Road Protection Scores (RPS)/Star Rating Scores (SRS) from engineering features, with safer 4–5-star roads having appropriate safety attributes for prevailing speeds, while 1–2-star roads lack the necessary safety features [14].

The iRAP Star Rating Score (SRS) is a critical metric used to assess road safety by evaluating various road attributes. Recent studies have explored the relationship between SRS and these attributes, providing insights into how road design and conditions impact safety. Road attributes significantly influence the SRS, which in turn correlates with safety performance indicators such as crash and fatality rates. For instance, a study in Indonesia found a positive correlation between higher SRS and increased safety performance indicators, although the relationship was not strongly linear (R^2 values between 0.2 and 0.7) [15]. In Ecuador, the SRS was recalibrated to fit local conditions better, suggesting that road attributes and their impact on safety can vary significantly by region [16]. Attributes such as roadside severity-object and roadside severity-distance have been identified as critical factors. A study in Croatia shows that a framework integrating mobile LiDAR and deep learning for these attributes achieved high classification accuracy, indicating their importance in determining SRS [17]. A study in Korea shows that pedestrian and roadside facilities were found to have a direct effect on crash numbers, highlighting the importance of these attributes in road safety assessments [7].

Implementing specific countermeasures, such as pedestrian fences, cycling signs, and speed limit signs, can significantly improve SRS. For example, improvements on Jenderal Sudirman Street in Indonesia led to notable increases in SRS for various road users [18]. In Pakistan, a comprehensive risk assessment and the implementation of countermeasures like pavement maintenance and traffic control devices were proposed to improve SRS and meet global road safety targets [19]. These studies underscore the importance of specific road attributes in determining the iRAP Star Rating Score.

Therefore, this study aims to systematically assess the road safety risk for motorcyclists in campus areas, with a specific focus on the role of local road attributes and traffic characteristics to propose suitable infrastructure-based countermeasures in reducing crash risk and injury severity.

2. RESEARCH METHOD

This study used primary and secondary data. Primary data consisted of observational data to determine traffic volume and road conditions. Secondary data consisted of motorcycle accident data collected by the UGM Office of Security, Occupational Safety, Emergency, and Environment (Kantor Keamanan, Keselamatan Kerja, Kedaruratan, dan Lingkungan/K5L). The accident data used were motorcycle accident data from July to December 2024. Accident data were obtained from road sections and intersections. This study used all motorcycle accident data recorded by K5L UGM. However, not all recorded data was included in the analysis. Only accidents occurring within the UGM campus area were included.

Observations of road conditions were conducted on the road sections and intersections where accidents occurred, as recorded in the K5L database. The road sections where accidents involving motorcycles happened during that period consisted of 12 road sections, which are Agro Road, Acasia Road, West Bhinneka Tunggal Ika Road, East Bhinneka Tunggal Ika Road, Notonegoro Road, Olahraga Road, Pancasila Road, Persatuan Road, Tevesia Road, South Teknika Road, Trengguli Road, and Yacaranda Road. Meanwhile, the analysis included 12 intersections, comprising roundabouts, unsignalized intersections, and signalized intersections. The roundabout intersections include the UGM Roundabout and the Olahraga Road Roundabout. Unsignalized intersections, which are the most common type of intersection, consist of nine intersections: the Olahraga Road – Agro Road intersection, the Olahraga Road – Sosio Yustisia Road intersection, the Olahraga Road – Fauna Road intersection, the Bhinneka Tunggal Ika Road – Tevesia Road intersection, the Bhinneka Tunggal Ika Road – Bungur Road intersection, the Bhinneka Tunggal Ika Road – Nusantara Road intersection, the Kesehatan Road – Grafika Road intersection, and the exit access of the UGM Central Administrative Office – Persatuan Road. The signalized intersection included in the analysis is the Colombo Road – Notonegoro Road – Herman Yohannes Road intersection.

Data analysis was conducted using the iRAP method. The star rating (SR) is calculated using the iRAP formula, which incorporates attributes of road and traffic conditions that influence the likelihood of an accident and the severity of the accident. Along with operational speed, traffic volume, and median conditions, these road attributes are assessed and summed for each possible accident type used in the iRAP method: run-off, head-on collision, intersections and access points, and moving along the road, to obtain a star rating score (SRS). Only motorcycle SRS were calculated in this study, as this study focuses on motorcycle safety.

A higher SRS indicates a lower level of safety at a location, or a lower SR. An SR of 1 indicates the least safe road conditions, while an SR of 5 indicates the safest road conditions [14]. Star ratings are applied to road sections, intersections, and intersection approaches where accidents involving motorcycles have occurred. The SRS values for each SR are 0 - <2.5 (SR 1), 2.5 - <5 (SR 2), 5 - <12.5 (SR 3), 12.5 - <22.5 (SR 4), and 22.5+ (SR 5).

Road attributes and traffic characteristics required in the star rating analysis to calculate the SRS consist of 64 variables, include roadside severity (distance and type of side objects), vehicle volume, speed limit, operational speed, visibility, intersections, paved shoulders, access points, number and width of lanes, slope, road condition, delineation, and the presence of rumble strips on shoulders, curves, traffic calming, service roads, and street lighting [20]. However, of the 64 variables, duplications were found, because one variable may be used in calculating the risk factors for several types of accidents that are taken into account in calculating the star rating score. Therefore, variable duplication is sorted. For road sections, 23 variables are used for analysis, and for intersections, 37 variables are used.

To determine the relationship between road conditions and accident risk, the star rating score (SRS) is linked to the road attributes. The dependent variable is SRS, and the independent variable is the road attributes. This relationship is explored using correlation and non-linear regression since the analyzed data are not normally distributed.

3. RESULTS AND DISCUSSION

3.1. Relationship between road attributes – traffic characteristics and Star Rating Score (SRS) at Road Sections

The relationship between road attributes – traffic characteristics and SRS for road sections has been analyzed through correlation and regression analysis.

For the correlation analysis, among 23 variables, the variables that have a significant correlation with SRS are curvature, median traversability, and operating speed. Further details on the correlation between road attributes – traffic characteristics and SRS can be seen in Table 1. Curvature is a road attribute that is considered in the calculation of the likelihood of the risk of run-off (driver and passenger side) and head-on (loss-of-control) crashes. Median traversability is a road attribute that is included in the calculation of the likelihood of the risk of run-off (driver side) and head-on (loss-of-control) crashes. Meanwhile, operating speed is a traffic component that influences all types of crash risks, which are run-off (driver and passenger side), head-on (loss-of-control and overtaking), and moving along the road crashes.

Research by Yang and Han points out that speed and volume have mediating (indirect) effects on the effects of road design on crash likelihood [7]. Higher speeds increase head-on and run-off crashes, which are partly due to the indirect effects of pedestrian and roadside facilities. Therefore, reducing vehicle speed can be an effective measure to reduce head-on and run-off crashes. Meanwhile, cross-section and curvature did not show direct associations with crash likelihood. Cross-section and curvature show associations through a mediating variable, which are speed and volume.

In this research, median traversability (a component of cross-section) and curvature show a significant correlation with SRS. This may be because the mediating effect of operating speed is not specifically analyzed in this research. Therefore, the significance of traversability and curvature emerges due to the mediating effects of operating speed, as has been identified in Yang and Han's research.

Table 1 - Correlation between road attributes – traffic characteristics and SRS at road sections

No.	Independent variables	Pearson Correlation	Sig. (2-tailed)
1	Lane width	.	.
2	Curvature	0,558	0,075
3	Quality of curve	.	.
4	Delineation	–0,088	0,797
5	Shoulder rumble strips	.	.
6	Road condition	–0,088	0,797
7	Grade	.	.
8	Skid resistance/grip	.	.
9	Roadside severity - distance	–0,266	0,430
10	Roadside severity - object	0,240	0,478
11	Paved shoulder width	0,129	0,705
12	External flow influence	.	.
13	Median traversability	0,588	0,057
14	Operating speed	0,592	0,055
15	Centreline rumble strips	.	.

16	Median type	0,171	0,444
17	Differential speeds	.	.
18	Number of lanes	0,024	0,944
19	Property access points	0,473	0,141
20	Service roads	0,193	0,570
21	Property access points	–0,024	0,944
22	Motorcycle facilities (likelihood)	.	.
23	Motorcycle facilities (severity)	.	.

Regression analysis is conducted by establishing the relationship between the dependent variable (SRS) and the independent variables (curvature, median traversability, and operating speed), which have already undergone correlation analysis. Various nonlinear regression models have been tried for this purpose. Exponential regression has been chosen since this regression shows the highest coefficient of determination (Adjusted R2), which is 0,961. The relationship between the independent variables (curvature, median traversability, and operating speed) and the dependent variable (SRS) can be seen in Equation 1.

$$\text{Ln } Y = 0{,}669 + 0{,}311(\text{curvature}) + 0{,}678\ (\text{median traversability}) + 16{,}170\ (\text{operating speed}) \quad (1)$$

The research reveals that SRS has a positive relationship with curvature, median traversability, and operating speed. This means that if the curvature has a higher value, indicating a sharper curve, then the SRS increases. For median traversability, a higher value indicates that the median can be traversed by a moving vehicle, suggesting a potential crash. This also applies to speed. Higher speeds lead to higher SRS values. Operating speeds around the UGM campus used in this research range from less than 30 km/h to 55 km/h.

3.2. Relationship between road attributes – traffic characteristics and Star Rating Score (SRS) at Intersections

The relationship between road attributes – traffic characteristics and SRS for intersections has been analyzed through correlation and regression analysis.

For the correlation analysis, among 37 variables, the variables that have a significant correlation with SRS are curvature (run-off-driver-side), roadside severity – distance, paved shoulder width, curvature (run-off-passenger-side), curvature (head-on-loss-of-control), intersection quality, intersection channelization, property access points (likelihood), and property access points (severity). Further details on the correlation between road attributes – traffic characteristics and SRS can be seen in Table 2.

Curvature is a road attribute that is considered in the calculation of the likelihood of the risk of run-off (driver and passenger side) and head-on (loss-of-control) crashes. Roadside severity distance is a road attribute considered in calculating the severity of run-off (driver and passenger side) crashes. Paved shoulder width is a road attribute considered in calculating the severity of run-off (driver and passenger side) crashes. Intersection quality is a road attribute considered in calculating the likelihood of intersection crashes. Intersection channelization is a road attribute considered in calculating the likelihood of intersection crashes. Property access point is a road attribute considered in calculating the likelihood and severity of crash risk due to the number of low-flow points where vehicles can enter or exit the roadway. This includes commercial and residential driveways and minor access lanes.

Table 2 - Correlation between road attributes – traffic characteristics and SRS at intersections

No.	Independent variables	Pearson Correlation	Sig. (2-tailed)
1	Lane width	.	.
2	Curvature (run-off-driver-side)	0,570	0,053
3	Quality of curve	.	.
4	Delineation	.	.
5	Shoulder rumble strips	.	.
6	Road condition	.	.
7	Grade	.	.
8	Skid resistance/grip	.	.

9	Roadside severity - distance	–0,846	0,001
10	Roadside severity - object	.	.
11	Paved shoulder width	–0,701	0,011
12	External flow influence	.	.
13	Median traversability	0,208	0,516
14	Operating speed	.	.
15	Curvature (run-off-passenger-side)	0,551	0,064
16	Curvature (head-on-loss-of-control)	0,664	0,019
17	Centreline rumble strips	.	.
18	Median type	0,208	0,516
19	Differential speeds	.	.
20	Number of lanes	0,058	0,859
21	Median type	0,204	0,525
22	Intersection type	0,168	0,601
23	Intersection quality	0,663	0,019
24	Grade	.	.
25	Street lighting	.	.
26	Skid resistance/grip	0,288	0,363
27	Sight distance	.	.
28	Intersection channelisation	0,637	0,026
29	Speed management/traffic calming	0,373	0,232
30	Intersection type	0,093	0,775
31	External flow influence	.	.
32	Operating speed	.	.
33	Property access points (likelihood)	0,768	0,004
34	Service roads	.	.
35	Property access points (severity)	0,768	0,004
36	Motorcycle facilities (likelihood)	.	.
37	Motorcycle facilities (severity)	.	.

Regression analysis is conducted by establishing the relationship between the dependent variable (SRS) and the independent variables (curvature (run-off-driver-side), roadside severity – distance, paved shoulder width, curvature (run-off-passenger-side and head-on-loss-of-control), intersection quality and channelization, property access points (likelihood and severity)), which have already undergone correlation analysis.

Various nonlinear regression models have also been tried for this purpose. Quadratic regression has been chosen since this regression shows the highest coefficient of determination (Adjusted R2), which is 0,913. The relationship between the independent variables (curvature (run-off-driver-side), roadside severity – distance, paved shoulder width, curvature (run-off-passenger-side and head-on-loss-of-control), intersection quality and channelization, property access points (likelihood and severity)) and the dependent variable (SRS) can be seen in Equation 2.

$$Y = 24{,}071 - 68{,}649\,(\text{road severity–distance})^2 + 45{,}809\,(\text{paved shoulder width}) - 41{,}952\,(\text{curvature (run-off-passenger-side)}) + 9{,}339\,(\text{curvature (head-on-loss-of-control)})^2 - 7{,}417\,(\text{intersection quality}) + 69{,}292\,(\text{intersection channelization}) + 0{,}600\,(\text{property access points (likelihood)})^2 \quad (2)$$

The research reveals that SRS has a negative relationship with road severity–distance, curvature (run-off-passenger-side), and intersection quality. The relationship between SRS and road severity-distance is also quadratic. Therefore, the negative value of the roadside severity-distance quadratic regression coefficient indicates that the relationship pattern between roadside severity-distance and SRS is curved downwards or inverted-U. This means that as the roadside-distance value increases, the SRS also increases until it reaches a certain point; beyond this point, the SRS will decrease. An increasing roadside distance value indicates that roadside obstacles are getting closer. This causes the SRS to increase. However, as the roadside distance gets closer, the SRS decreases. This could be because motorcyclists are becoming more cautious when approaching obstacles.

Meanwhile, the relationship between SRS and curvature (run-off-passenger-side) and intersection quality is linear but negative, indicating that as curvature (run-off-passenger-side) and intersection quality increase, SRS will decrease. The higher the curvature value, the sharper the curvature. And the higher the intersection quality value, the worse the quality of the intersection. However, with increasingly sharp curves or poor-quality intersections, this may cause motorcyclists to be more careful, resulting in a lower SRS.

The research reveals that SRS has a positive relationship with paved shoulder width, curvature (head-on-loss-of-control), intersection channelization, and property access points (likelihood). The relationship between SRS and paved shoulder width and intersection channelization is also linear. This means that with increasing paved shoulder width and intersection channelization values, SRS will increase. An increase in the paved shoulder width value means that the paved shoulder width is getting narrower or even nonexistent. An increase in the intersection channelization value likely indicates that there is no channelization at that intersection.

Meanwhile, the relationship between SRS and curvature (head-on-loss-of-control) and property access points (likelihood) is also quadratic. This means that the relationship pattern between curvature (head-on-loss-of-control) and property access points (likelihood) and SRS is curved upwards or U-shaped. This means that as the curvature (head-on-loss-of-control) and property access points (likelihood) value increase, the SRS decreases until it reaches a certain point; beyond this point, the SRS will increase. An increasing curvature (head-on-loss-of-control) value indicates that the curve is sharper. However, the SRS decrease means that the motorcyclists will be more careful when passing through this curve, so the risk of a head-on crash decreases. However, when the curve becomes sharper, the road becomes very dangerous due to the difficulty in controlling the motorbike's movement when cornering, perhaps with limited visibility. The increase in the value of the property access point suggests that land use around the intersection is resulting in more intense low-speed vehicle movement in and out. This will lower the SRS as motorcyclists become more cautious to anticipate incoming and outgoing vehicles. However, as more vehicles enter and exit, conditions will become more crowded and conflict points will increase, causing the SRS to rise again.

4. CONCLUSION

The road attributes that play the most crucial role in determining the SRS value for a motorcycle on a road segment in the UGM campus area are those that contribute to accident likelihood: curvature, median transversability, and operating speed. Although previous research has shown operating speed to be a mediating variable rather than a direct factor in accident occurrence, it is essential to consider the factors that contribute to accidents. For intersections, the road attributes that significantly determine the level of safety are those that influence the likelihood and severity. The road attributes that influence likelihood are curvature, intersection quality, channelization, and property access points. The road attributes that influence severity are roadside severity – distance, paved shoulder width, and property access points. Based on the most significant road attributes and their influence on SRS, road safety improvements for motorcycles can be made by improving the quality of these road attributes.

This research was conducted on the road section and intersection where the accident occurred. Future research could be conducted on all roads and intersections within the UGM campus area. Research needs to be conducted over a longer period of time to obtain stable and unbiased accident data trends.

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