



Multi-method accident blackspot analysis using EAN, UCL and chain of event: Evidence from Indonesian urban roads

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Abstract

Traffic accidents cause 1.19 million deaths annually globally, with 90% occurring in middle-income countries. Indonesia faces a critical challenge with motorcycles accounting for 84-85% of vehicles and contributing to 73% of traffic accidents. This study proposes an integrated analytical framework combining the Equivalent Accident Number (EAN)-Upper Control Limit (UCL) method for statistical blackspot identification, Chain of Event analysis for causality mechanism investigation, and iRAP Star Rating assessment for infrastructure risk evaluation. The framework is demonstrated on Jalan Slamet Riyadi, Surakarta, a 5.7 km urban arterial road with 414 accidents (2020-2024), the highest frequency in the city. The EAN-UCL analysis identifies two critical blackspot segments (STA 0+000-0+500 and STA 4+000-4+500). Chain of Event analysis revealed that accidents occurred in the form of out-of-control collisions, front-to-rear collisions and collisions at intersections with a causal path from hazard existence (uncontrolled intersections, high side obstacles) through precipitating events (loss of control) to crash events. The initial iRAP assessment showed that segments had an average rating of 2 and 3 stars, with the lowest score for pedestrians (<2). Based on the integration of the three methods, specific recommendations included: speed limit signs, physical road medians, zebra crossing improvements and reflective edge markings. Post-intervention evaluation showed significant improvements: both segments' ratings increased to 4 stars with the lowest score for pedestrians (>2), and improved scores for all road user categories. This multi-method framework proved its effectiveness in identifying blackspots, understanding causal mechanisms and predicting the effectiveness of interventions for motorcycle-dominated urban roads in Indonesian.

Keywords

Blackspot, Accident, EAN-UCL, Chain of event, iRAP, Star rating

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Introduction

Road traffic accidents remain a major global public safety issue, causing approximately 1.19 million deaths annually, with vulnerable road users dominating fatalities, particularly in low- and middle-income countries [1][2]. The risk is especially high in Southeast Asia where motorcycles dominate daily transport and infrastructure and enforcement remain limited [3]. In Indonesia, motorcycles account for about 84–85% of the vehicle fleet and contribute more than 70% of traffic fatalities, especially on heterogeneous urban roads with dense access points and high roadside activity [4][5][6][7][8][9]. High intersection density and limited visibility increase conflict frequency, with side-impact collisions becoming the dominant crash type and motorcycle vulnerability increasing crash severity [3][10][11][12][13]. Therefore, identifying accident-prone locations is essential for targeted safety interventions [14].

Road safety analysis commonly begins with blackspot identification using Equivalent Accident Number (EAN) and Upper Control Limit (UCL), which effectively detect high-risk locations but do not explain causal mechanisms or infrastructure-related risks [15][16][17][18][19][20][21]. To address these limitations, recent studies integrate infrastructure-based risk assessment using the International Road Assessment Programme (iRAP) with causal modelling through the Chain of Events framework [22][23][26][27]. However, integrated multi-method studies on motorcycle-dominated urban corridors remain limited [24][25]. Therefore, this study proposes an integrated framework combining EAN-UCL, Chain of Events, and iRAP, applied to Jalan Slamet Riyadi in Surakarta, a 5.7 km urban arterial corridor with 414 accidents recorded during 2020–2024, to provide a more comprehensive safety evaluation for motorcycle-dominated urban traffic conditions.

Method

Study area and data

The study was conducted on Jalan Slamet Riyadi, Surakarta, a 5.7 km urban arterial corridor characterized by commercial activity and dominant motorcycle traffic. The location was selected due to high accident frequency (414 crashes during 2020–2024), motorcycle dominance (>80%), numerous uncontrolled access points, and mixed land use. Data consisted of police accident records, iRAP-based field surveys, and field observations. The road was divided into 500-meter segments.

Analytical methods

This study employs a mixed analytical–numerical methodology combining statistical accident analysis, crash mechanism modeling, and infrastructure-based risk evaluation, as illustrated in [Figure 1](#).

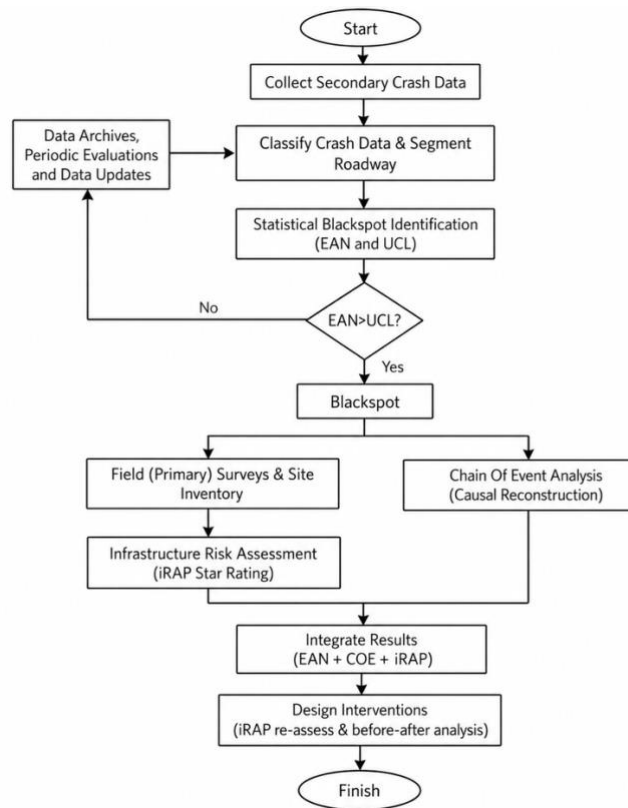


Figure 1. Research flow

Blackspot identification was performed using the Equivalent Accident Number (EAN) and Upper Control Limit (UCL) methods, where accident severity was converted into weighted values based on fatalities, serious injuries, and minor injuries [28]. Segments with EAN values exceeding the UCL threshold were classified as accident-prone locations. The identified blackspot segments were then analyzed using the Chain of Events (CoE) approach to determine sequential crash mechanisms consisting of hazard existence, precipitating events, unsafe situations, crash events, and consequences based on accident data and field observations [29][30]. Furthermore, infrastructure-based risk assessment was conducted using the iRAP Star Rating methodology, which predicts crash risk from road attributes coded at 100-meter intervals and processed using ViDA software [31][32]. Reassessment was carried out after proposed interventions to estimate potential safety improvements. The study utilized five-year crash data, field observation sheets, and iRAP coding instruments, while potential limitations include underreporting in crash data and subjectivity in infrastructure coding.

Integrated multi-method framework and limitations

The integration of EAN-UCL, CoE, and iRAP links crash frequency, crash mechanisms, and infrastructure risk to produce comprehensive safety recommendations. Limitations include possible underreporting of crash data, subjectivity in infrastructure coding, and the predictive nature of iRAP scores.

Results

Blackspot identification

Blackspot identification was conducted for all 500-meter segments along Jalan Slamet Riyadi using the EAN–UCL method. The results indicate that only two segments, STA 0+000–0+500 and STA 4+000–4+500, have EAN values exceeding the UCL threshold and are therefore classified as blackspots. These segments also recorded the highest accident frequencies during 2020–2024 and were selected for further analysis [Table 1](#).

Table 1. Blackspot identification

Stationing	EAN	UCL	Description
0+000 – 0+500	210	174.9854	Blackspot
4+000 – 4+500	174	172.6455	Blackspot

Chain of events analysis on blackspot segments

Segment STA 0+000–0+500 is dominated by rear-end crashes (9), followed by out-of-control (7) and intersection crashes (7). Segment STA 4+000–4+500 is dominated by out-of-control (9) and intersection crashes (7), particularly near major intersections and railway crossings. The summarized crash mechanisms based on the Chain of Events approach are presented in [Table 2](#).

Table 2. Chain of events summary for blackspot segments

Accident Type	Chain of Event Stage	Event Description	
		Stationing 0+000 – 0+500	Stationing 4+000 – 4+500
Out of Control	Hazard & Trigger	High traffic volume, roadside barriers, sudden braking.	No median, railway crossing, high speed
	Unsafe Condition	No shoulder and limited recovery space.	Narrow space and roadside obstacles
	Crash Impact	Single-vehicle skid or roadside collision.	Skid or collision with roadside objects
Intersection Collisions	Hazard & Trigger	Dense commercial intersections.	Uncontrolled multi-leg intersections
	Unsafe Condition	Priority violations and late braking.	Weak control and limited visibility
	Crash Impact	Side-on collisions.	Motorcycle–vehicle conflicts
Rear-end Collisions	Hazard & Trigger	High traffic density and frequent access.	-
	Unsafe Condition	Short following distance and limited reaction time.	-
	Crash Impact	Front-to-rear collision.	-

The results show that at STA 0+000–0+500, rear-end crashes are mainly related to high traffic density and unsafe following distance, while out-of-control crashes are associated with sudden braking and the absence of safe shoulders. Intersection crashes are linked to priority violations in dense commercial areas. At STA 4+000–4+500, intersection crashes are influenced by insufficient control on minor approaches, while out-of-control crashes are related to railway crossings and sudden braking.

Risk assessment using iRAP

The distribution of safety levels based on the iRAP assessment for both segments is presented in Figure 2.

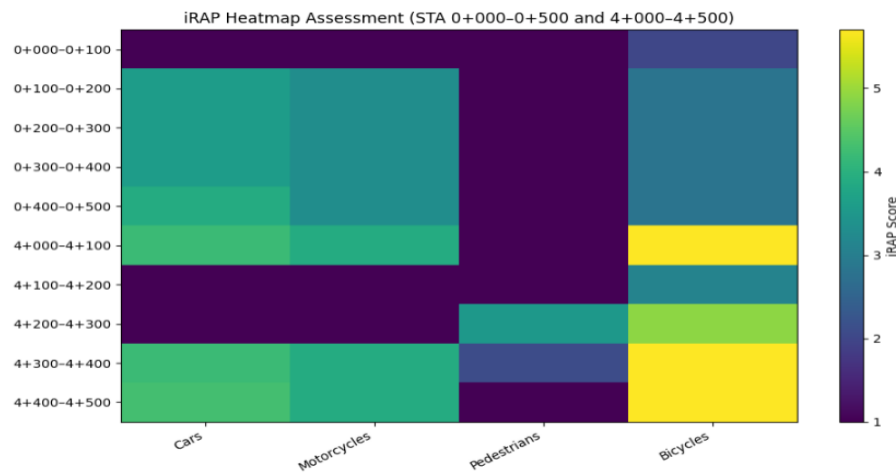


Figure 2. Assessment of iRAP stationing 0+000 – 0+500

The initial iRAP assessment indicates that segment STA 0+000–0+500 has a relatively low safety level with iRAP scores of: cars 3.6–3.9; motorcycles 3.3; pedestrians 1.0; and cyclists 2.8, with an overall rating of 3 stars. Segment STA 4+000–4+500 shows greater variation with scores of: cars 1.0–4.3; motorcycles 1.0–3.9; pedestrians 1.0–3.5; and cyclists 3.1–5.7, producing ratings between 1 and 4 stars across several sub-segments.

Integration of findings (EAN-UCL, CoE, iRAP)

The relationship between crash mechanisms based on Chain of Events and infrastructure risk factors based on iRAP is summarized in Table 3.

Table 3. Integration of CoE–iRAP relationship analysis

Segment	Dominant Crash Type	CoE Critical Factors	iRAP Low-Score Dimensions
STA 0+000 – 0+500	Rear-end (9), Out of-Control (7), Intersection (7)	High speed, dense traffic, high side obstacles, no safe shoulder, poor intersection control	Roadside Severity, Speed Management, Intersection Quality
STA 4+000 – 4+500	Out-of-Control (9), Intersection (7), Rear-end (5)	Railway tracks, high side obstacles, poor intersection control, limited visibility	Roadside Severity, Intersection Quality, Railway Crossing Safety

The alignment of these findings indicates that safety recommendations should focus on speed management, intersection improvements, access management, and enhanced protection for vulnerable road users to ensure more targeted interventions.

Post-intervention iRAP evaluation

Post-intervention iRAP evaluation was conducted for both priority segments based on the integrated analysis results. At STA 0+000–0+500, recommended measures include speed management through a 40 km/h limit, installation of a 1.5 m raised median (PUPR Regulation No. 5/2023), improvement of pedestrian crossings using thermoplastic

markings, and reflective edge markings to enhance visibility. At STA 4+000–4+500, countermeasures include rumble strips on intersection approaches, provision of right-turn pockets, and improved directional pavement markings to reduce conflict points (Figure 3).



Figure 3. Intervention recommendations for STA 0+000–0+500 (a) and 0+000–0+500 (b)

Based on these improvements, an iRAP evaluation before and after intervention was conducted as presented in Table 4.

Table 4. iRAP evaluation before and after intervention

Segment	Condition	cars	Motorcycles	Pedestrians	Bicycles	Star Rating
0+000 – 0+500	Before/After	3.7/4.5	3.3/4.3	1.0/3.5	2.8/3.9	3☆/4★
4+000 - 4+500	Before/After	2.9/3.4	2.7/3.2	1.7/2.7	5.0/5.4	2☆/4★

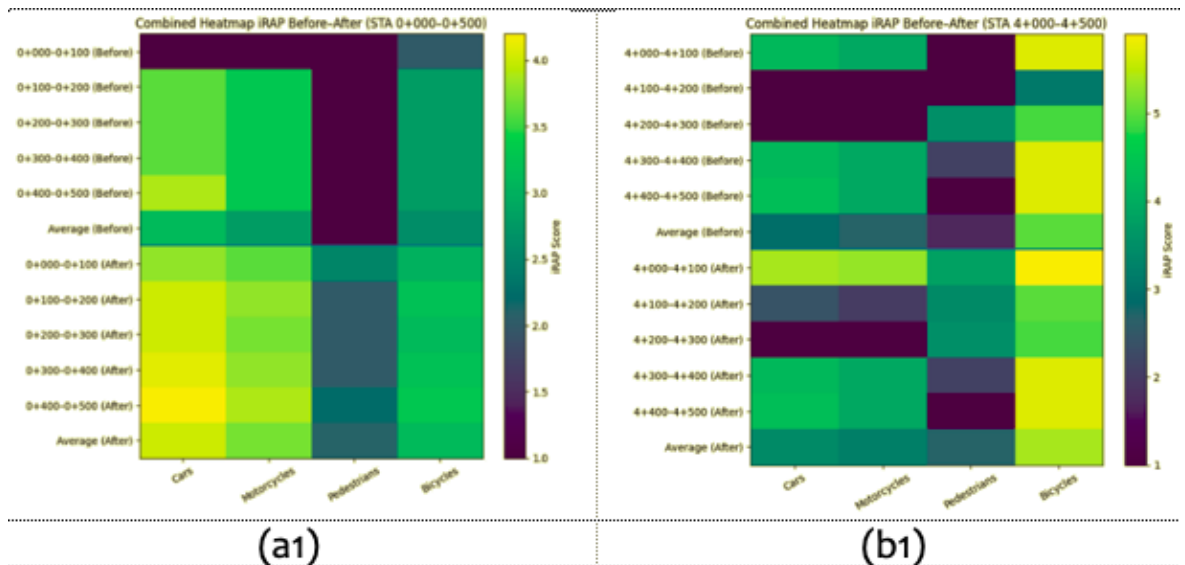


Figure 4. iRAP heatmap comparison before–after intervention for STA 0+000–0+500 (a1) and 0+000–0+500 (b1)

The results show significant safety improvement at both segments after intervention (Table 4). At STA 0+000–0+500, the Star Rating increased from 3 to 4 due to improvements in pedestrian facilities and speed control. At STA 4+000–4+500, the rating increased from 2 to 4 following intersection treatment and traffic calming measures. The comparative visualization of iRAP scores is presented in Figure 4.

Discussion

The findings indicate that segments STA 0+000–0+500 and STA 4+000–4+500 have the highest accident risk based on the integration of EAN–UCL, CoE, and iRAP methods, consistent with urban corridor characteristics where blackspots occur under high traffic flow, strong roadside friction, and inadequate infrastructure [18][19]. Both segments exceed the UCL threshold, while the integration of the Chain of Events approach addresses the limitation of EAN-UCL in explaining causal mechanisms [17].

At STA 0+000–0+500, the dominance of rear-end and out-of-control crashes reflects problems related to operating speed, unsafe following distance, roadside friction, sudden braking, and the absence of safe shoulders [15] [22] [23]. At STA 4+000–4+500, crashes are mainly associated with inadequate intersection control, limited visibility, and additional risks from parallel railway tracks [20]. The iRAP assessment supports these findings by showing consistency between crash mechanisms and infrastructure deficiencies, particularly low pedestrian protection. Previous studies also confirm the relationship between low iRAP scores and crash rates, and this study extends the evidence to motorcycle-dominated urban arterial roads [26]. Overall, the integration of EAN-UCL, CoE, and iRAP provides a comprehensive basis for evidence-based safety recommendations.

Conclusion

This study evaluates the safety of Slamet Riyadi Road by integrating EAN-UCL, Chain of Events (CoE), and iRAP approaches. Two accident-prone segments (STA 0+000–0+500 and STA 4+000–4+500) were identified with EAN values exceeding UCL thresholds. CoE analysis indicates that rear-end crashes are related to unsafe following distance, out-of-control crashes to roadside obstacles and lack of shoulders, and intersection crashes to weak traffic control. These findings confirm the interaction between driver behavior and infrastructure conditions. The iRAP assessment identifies key deficiencies in speed management, roadside protection, intersection visibility, and pedestrian facilities. The integration of the three methods provides a more comprehensive evaluation framework than single-method approaches. Proposed interventions such as medians, rumble strips, markings, and speed control improved the predicted iRAP ratings, indicating that targeted infrastructure improvements can significantly enhance safety. This study contributes an integrated road safety evaluation framework for motorcycle-dominated urban corridors. Future studies are recommended to include traffic flow, weather variables, and microsimulation for more detailed safety prediction.

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Reference

- [1] World Health Organization, "Global status report on road safety 2023," *World Health Organization*, 2023. <https://www.who.int/publications/i/item/9789240086517>
- [2] World Bank, "A decade of saving lives through road safety investments.," *Washington, DC*, 2024. <https://www.worldbank.org/en/results/2024/03/25/a-decade-of-saving-lives-through-road-safety-investments>
- [3] Y. Kitamura, M. Hayashi, and E. Yagi, "Traffic problems in Southeast Asia featuring the case of Cambodia's traffic accidents involving motorcycles," *IATSS Res.*, vol. 42, no. 4, pp. 163–170, 2020, doi: 10.1016/j.iatssr.2018.11.001.
- [4] A. Jusuf, I. P. Nurprasetio, and A. Prihutama, "Macro Data Analysis of Traffic Accidents in Indonesia," vol. 49, no. 1, pp. 132–143, 2017, doi: 10.5614/j.eng.technol.sci.2017.49.1.8.
- [5] K. N. S. Ayuningtyas, R. Grzebieta, and J. Olivier, "Addressing Indonesia's biggest road safety challenge: Reducing motorcycle deaths Addressing Indonesia's biggest road safety challenge: Reducing motorcycle deaths," 2024, doi: 10.1088/1755-1315/1294/1/012013.
- [6] N. S. Kusumastutie, B. Patria, S. Kusrohmaniah, and T. D. Hastjarjo, "Hazardous traffic scenarios for motorcyclists in Indonesia: a comprehensive insight from police accident data and self-reports," *Int. J. Inj. Contr. Saf. Promot.*, vol. 31, no. 3, pp. 408–419, Jul. 2024, doi: 10.1080/17457300.2024.2335495.
- [7] W. Halim, M. Arlini, R. Aji, and B. Prasetyo, "Understanding motorcycle rider behavior and the related traffic contexts in Indonesia using naturalistic driving study," *Heliyon*, vol. 11, no. 4, p. e42494, 2025, doi: 10.1016/j.heliyon.2025.e42494.
- [8] N. S. Kusumastutie, B. Patria, S. Kusrohmaniah, and T. D. Hastjarjo, "A review of accident data for traffic safety studies in Indonesia A review of accident data for traffic safety studies in Indonesia", doi: 10.1088/1755-1315/1294/1/012012.
- [9] T. Yuan, X. Zeng, and T. Shi, "Identifying Urban Road Black Spots with a Novel Method Based on the Firefly Clustering Algorithm and a Geographic Information System," no. December 2018, 2020.
- [10] P. Pechteep, P. Luathep, S. Jaensirisak, and N. Kronprasert, "Analysis of Factors Influencing Driver Yielding Behavior at Midblock Crosswalks on Urban Arterial Roads in Thailand," pp. 1–25, 2024.
- [11] H. Ospina-Mateus, L. Quintana Jiménez, and F. J. López-Valdés, "Analyzing traffic conflicts and the behavior of motorcyclists at unsignalized three-legged and four-legged intersections in Cartagena, Colombia," *Accid. Anal. Prev.*, vol. 191, 2023, doi: 10.1016/j.aap.2023.107222.
- [12] Z. Lai, D. Zhang, Y. Peng, and J. Yang, "Study of head injuries to motorcycle riders and passengers in car and motorcycle collision accidents," pp. 1–14, 2025.
- [13] E. Giovannini et al., "Motorcycle injuries : a systematic review for forensic evaluation," pp. 1907–1924, 2024.
- [14] S. Hadi, S. I. Wahyudi, K. Wibowo, F. Tohom, and Z. S. Putri, "Day and Night Blackspots Analysis on Semarang-Solo Toll Road: Mitigation Strategies to Enhance Traffic Safety," in *IOP Conference Series: Earth and Environmental Science*, 2025, vol. 1543, no. 1. doi: 10.1088/1755-1315/1543/1/012042.
- [15] S. Rejali, K. Aghabayk, M. Seyfi, and O. Oviedo-trespalacios, "Assessing distracted driving crash severities at New York City urban roads : A temporal analysis using random parameters logit model," *IATSS Res.*, vol. 48, no. 2, pp. 147–157, 2024, doi: 10.1016/j.iatssr.2024.03.003.
- [16] C. Dong and N. Chang, "Overview of the identification of traffic accident-prone locations driven by big data," *Digit. Transp. Saf.*, vol. 2, no. 1, pp. 67–76, 2023, doi: 10.48130/DTS-2023-0006.
- [17] C. Zhang et al., "A systematic review of the application and prospect of road accident blackspots identification approaches," *Transp. Lett.*, vol. 17, no. 6, pp. 1114–1137, Jul. 2025, doi: 10.1080/19427867.2024.2416304.
- [18] S. Alam and N. J. Tabassum, "Spatial pattern identification and crash severity analysis of road traffic crash hot spots in Ohio," *Heliyon*, vol. 9, no. 5, p. e16303, 2023, doi: 10.1016/j.heliyon.2023.e16303.
- [19] W. Treeranurat and S. Suanmali, "Determination of black spots by using accident equivalent number and upper control limit on rural roads of Thailand," *Eng. Manag. Prod. Serv.*, vol. 13, no. 4, 2021, doi: 10.2478/emj-2021-0031.
- [20] P. Wu, T. Chen, Y. D. Wong, X. Meng, X. Wang, and W. Liu, "Exploring key spatio-temporal features of crash risk hot spots on urban road network: A machine learning approach," *Transp. Res. Part A Policy Pract.*, vol. 173, 2023, doi: 10.1016/j.tra.2023.103717.
- [21] I. Karamanlis et al., "Deep Learning-Based Black Spot Identification on Greek Road Networks," pp. 1–27, 2023.
- [22] K. Singh, J. Maiti, and K. Dhalmahapatra, "Chain of events model for safety management: Data analytics approach," *Saf. Sci.*, vol. 118, 2019, doi: 10.1016/j.ssci.2019.05.044.

- [23] L. M. Wong and T. Pawlicki, "A review of accident models and incident analysis techniques," no. August 2024, pp. 1–18, 2025, doi: 10.1002/acm2.14623.
- [24] A. Paliotto, M. Meocci, A. Terrosi, and F. La Torre, "Systematic review, evaluation and comparison of different approaches for the implementation of road network safety analysis," *Heliyon*, vol. 10, no. 7, 2024, doi: 10.1016/j.heliyon.2024.e28391.
- [25] F. Chen, Y. Zhu, J. Zu, J. Lyu, and J. Yang, "Appraising road safety attainment by CRITIC-ELECTRE-FCM: A policymaking support for Southeast Asia," *Transp. Policy*, vol. 122, 2022, doi: 10.1016/j.tranpol.2022.04.014.
- [26] K. N. S. Ayuningtyas, A. Kusumawati, S. H. Pangestika, and I. Hadiyanti, "The Relationships Between iRAP Star Rating Score and Various Safety Performance Indicators," vol. 15, no. June 2022, pp. 1349–1360, 2024, doi: 10.14716/ijtech.v15i5.5726.
- [27] A. K. Jameel and H. T. Evdorides, "Review Of Modifying The Indicators Of Road Safety System," *Journal of Engineering and Sustainable Development*, vol. 27, no. 2. 2023. doi: 10.31272/jeasd.27.2.1.
- [28] A. Paikun, P., Faris, W., & Rozandi, "Traffic Accident Point Analysis, On Primary Arterial Road-Sukabumi District," *ASTONJADRO*, vol. 10, no. 2, pp. 237–248, 2021, [Online]. Available: <http://150.107.142.43/index.php/ASTONJADRO/article/view/5471/0>
- [29] B. L. Turner *et al.*, "Chain of events analysis in diving accidents treated by the Royal Netherlands Navy 1966-2023," *Diving Hyperb. Med.*, vol. 54, no. 1, 2024, doi: 10.28920/dhm54.1.39-46.
- [30] S. Bao, T. Li, and B. Cao, "Chain-of-event prompting for multi-document summarization by large language models," *Int. J. Web Inf. Syst.*, vol. 20, no. 3, 2024, doi: 10.1108/IJWIS-12-2023-0249.
- [31] D. M. Shokat and A. K. Jameel, "Identifying the Crash Worthiness and Crash Avoidance Factors Based on Road Features," in *E3S Web of Conferences*, 2023, vol. 427. doi: 10.1051/e3sconf/202342703010.
- [32] D. O. Dubila, J. F. Wounba, S. K. Fondzenyuy, N. T. Lordswill, and N. G. Elambo, "Evaluating Road Infrastructure Safety in Bamenda, Cameroon: A Data-Driven Approach Using Reactive Safety Performance Indicators and iRAP Star Ratings," *Int. J. Transp. Logist. Res.*, vol. 1, no. 1, 2025, doi: 10.53941/ijtlr.2025.100003.