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Collision Diagram Analysis and Weighted Ranking of Accident-Prone Areas (Black Spots) on the Road Network of Padangsidimpuan City

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Abstract

Padangsidimpuan City records traffic accidents concentrated on several road segments, yet mitigation efforts have generally focused on identifying accident-prone locations without examining collision characteristics. This study aims to rank accident-prone areas (black spots) using a multi-criteria weighting method, analyze collision patterns through collision diagrams, identify dominant contributing factors, examine the relationship between road geometry, vehicle speed, and accident patterns, and formulate segment-specific countermeasures. A quantitative descriptive approach was employed using 2021 traffic accident records from the Padangsidimpuan Traffic Police together with field surveys of road geometry and spot speeds. Black-spot ranking was based on casualty severity, road function, road status, and material losses. The results identified Jenderal Sudirman Road as the highest-ranked black spot (score = 49), followed by H.T. Rizal Nurdin Road (47), Abdul Haris Nasution 1 Road (35), Raja Inal Siregar Road (31), and Imam Bonjol Road (30). Collision diagram analysis identified head-on collisions as the dominant crash pattern, with Jenderal Sudirman Road recording the highest proportion (5 of 9 crashes; 55.6%). Human factors, particularly excessive speed and driver negligence, were the dominant contributing factors, reinforced by inadequate road infrastructure, including the absence of speed-limit signs, black-spot warning signs, and median separation. The study recommends speed management measures, installation of warning signs and rumble strips, median or centerline improvements, and implementation of a School Safety Zone (ZoSS) on school-front road segments. These findings provide practical guidance for transportation agencies and road authorities in prioritizing data-driven road safety improvements.

Keywords: *traffic accident; black spot; collision diagram; multi-criteria weighting; road safety*

1. INTRODUCTION

Traffic safety is a key indicator of transportation system performance. Indonesian Law No. 22 of 2009 defines road safety as a condition in which road users are protected from accident risks caused by human, vehicle, roadway, and environmental factors, highlighting the multi-factorial nature of traffic accidents. Globally, traffic accidents remain a major public health issue, causing more than one million deaths annually, with low- and middle-income countries accounting for the largest proportion of fatalities (WHO, 2018).

In Padangsidimpuan City, increasing transportation demand has not been matched by equivalent improvements in road infrastructure. Traffic Police records show 247 accidents during 2017–2021, resulting in 99 fatalities, 132 serious injuries, and 129

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minor injuries, with accidents concentrated on several road segments identified as black spots. Although black-spot studies commonly rank hazardous locations based on accident frequency or severity, such approaches do not adequately explain collision characteristics, often resulting in generalized countermeasures.

One effective tool for understanding accident characteristics is the collision diagram, which systematically maps accident locations, chronology, and collision types to identify dominant crash patterns (Direktorat Jenderal Perhubungan Darat, 2007). Previous studies in Padangsidimpuan focused separately on Jenderal Sudirman Road (Maulana, 2022) and Abdul Haris Nasution 1 Road (Nauval, 2022), but none integrated multi-criteria black-spot ranking, collision diagram analysis, contributing-factor identification, and pattern-based countermeasures within a single analytical framework.

Accordingly, this study combines a multi-criteria weighting method with collision-diagram analysis to identify priority black spots, examine dominant collision patterns and contributing factors, evaluate the influence of vehicle speed, road geometry, and safety facilities, and formulate targeted engineering recommendations. This integrated approach provides a more comprehensive basis for road safety planning and black-spot management in Padangsidimpuan City.

2. METHOD

This study employed a quantitative descriptive approach using both secondary and primary data to identify and analyze traffic accident black spots in Padangsidimpuan City, North Sumatra. The study focused on five priority road segments: Jenderal Sudirman Road, H.T. Rizal Nurdin Road, Imam Bonjol Road, Abdul Haris Nasution 1 Road, and Raja Inal Siregar Road.

The analyzed variables included accident frequency, casualty severity (fatalities, severe injuries, and minor injuries), material losses, road status and function, collision type and chronology, vehicle operating speed, roadway geometric characteristics, and road safety facilities. Secondary data consisted of 2021 traffic accident records obtained from the Padangsidimpuan Traffic Police, road inventory data, traffic volume, geometric data, and supporting documents from previous PTDI-STTD field studies. Primary data were collected through field observations, road-furniture inventories, geometric measurements, and spot-speed surveys.

Vehicle speeds were measured using a speed gun and analyzed using the 85th-percentile speed approach. Road geometry was evaluated by calculating the Stopping Sight Distance (SSD) according to AASHTO (1990) and the minimum horizontal curve radius using:

$$R_{\min} = \frac{V^2}{127(e_{\max} + f_{\max})}$$

where R is the minimum curve radius (m), V is the operating speed (km/h), e is the maximum superelevation, and f is the maximum side-friction coefficient (Sukirman, 1999).

Data analysis consisted of eight stages: (1) multi-criteria weighting to rank black-spot locations based on casualty severity, road status, road function, and material losses; (2) casualty-severity analysis; (3) collision diagram construction based on accident

chronology and collision type; (4) spot-speed analysis using the 85th-percentile speed; (5) geometric analysis through SSD and minimum curve-radius calculations; (6) identification of contributing factors involving human, vehicle, roadway, and environmental aspects; (7) comparative analysis among priority road segments and previous studies; and (8) descriptive statistical analysis to present and interpret the findings. The overall research procedure is illustrated in **Figure 1**.

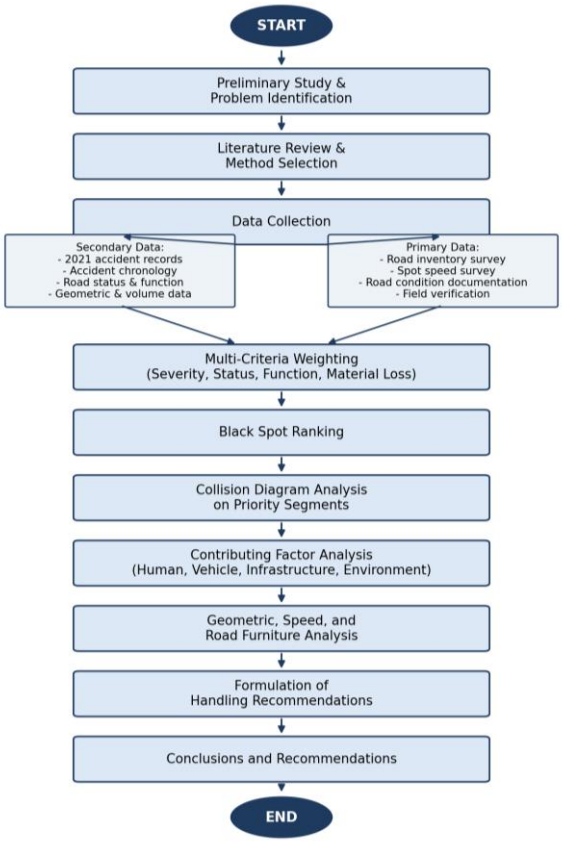

Figure 1. Research Flowchart

3. RESULTS AND DISCUSSION

Results

a. Characteristics of the Study Road Segments

Padangsidimpuan City has 34 road segments with a total length of 70.77 km, comprising 13 national road segments (27.8 km), 14 provincial road segments (18.55 km), and 8 city road segments (24.42 km), with pavement generally consisting of asphalt. From this network, this study focuses its analysis on the five road segments with the highest black-spot weighted scores in 2021, as presented in Table 1.

Table 1. Characteristics of the Study Road Segments

No	Road Name	Segment Length	Road Type	Road Status	Road Function	Effective Lane Width
1	Jenderal Sudirman Rd.	1.05 km	2/2 UD	Provincial	Collector	6 m
2	H.T. Rizal Nurdin Rd.	Not available*	Not available*	National	Arterial	Not available*
3	Abdul Haris Nasution 1 Rd.	6.10 km	2/2 UD	Provincial	Collector	6 m
4	Raja Inal Siregar Rd.	Not available*	Not available*	National	Arterial	Not available*
5	Imam Bonjol Rd.	Not available*	Not available*	National	Primary Arterial	Not available*

Table 1 shows that two of the five priority segments-Jenderal Sudirman Road and Abdul Haris Nasution 1 Road-have provincial status with collector function, while the other three segments have national status with arterial function.

b. Weighting and Ranking of Accident-Prone Areas (Black Spots)

Black-spot locations were determined using a multi-criteria weighting method considering four aspects: casualty severity, road function, road status, and material losses. The weighting scheme used, consistent with the 2021 weighting results obtained from the Padangsidimpuan Traffic Police, is presented in Table 2.

Tabel 2. Weighting Scheme for Black Spot Determination

Criterion	Category	Weight Value
Casualty Severity	Fatality (F)	6
	Severe Injury (SI)	3
	Minor Injury (MI)	1
Road Status	National	5
	Provincial	3
	City/Regency	1
Road Function	Arterial	5
	Collector	3
	Local	1
Material Loss	Large	6
	Moderate	3
	Small	1

The total weighted score for each road segment was obtained by summing the product of the number of casualties in each severity category with its weight, plus the weight values for road function, road status, and material loss. The ranking results for the five road segments with the highest weighted scores in Padangsidimpuan City in 2021 are presented in Table 3.

Tabel 3. Ranking of Accident-Prone Areas (Black Spots) in Padangsidimpuan City, 2021

Road Name	No. of Accidents	F	SI	MI	Road Function	Road Status	Material Loss (Rp)	Total Score	Rank
Jenderal Sudirman Rd.	9	4	5	3	Collector	Provincial	3,000,000	49	1
H.T. Rizal Nurdin Rd.	7	3	4	6	Arterial	National	16,800,000	47	2
Abdul Haris Nasution 1 Rd.	4	4	1	1	Collector	Provincial	2,200,000	35	3
Raja Inal Siregar Rd.	3	2	1	3	Arterial	National	50,800,000	31	4
Imam Bonjol Rd.	4	1	3	4	Arterial	National	700,000	30	5

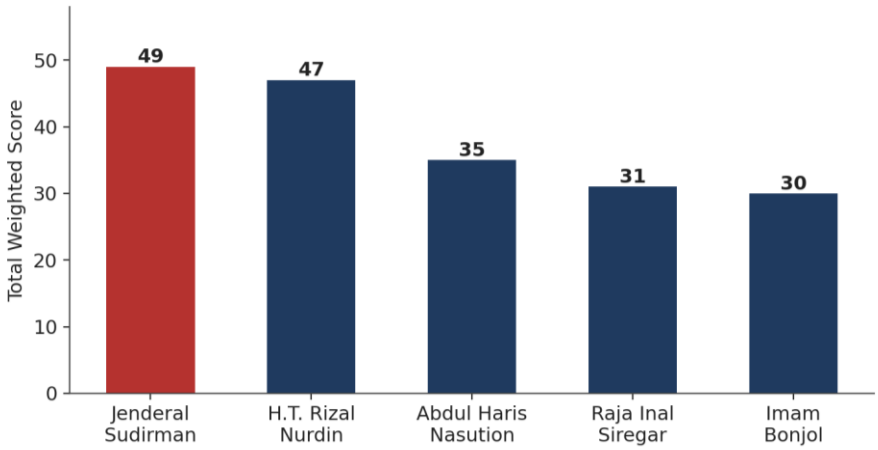

Figure 2. Comparison of Black Spot Weighting Results Across Road Segments

Figure 3. Multi-Criteria Weighting Structure for Black Spot Determination

Based on Table 3 and Figure 2, Jenderal Sudirman Road ranks first with a total score of 49, followed by H.T. Rizal Nurdin Road (47), Abdul Haris Nasution 1 Road (35), Raja Inal Siregar Road (31), and Imam Bonjol Road (30). Interpretation of these ranking results is presented further in Section 4.1.

c. Accident Characteristics on Priority Road Segments

The accident characteristics of the five priority road segments in 2021, in terms of number of events and casualty severity, are presented in Figures 4 and 5.

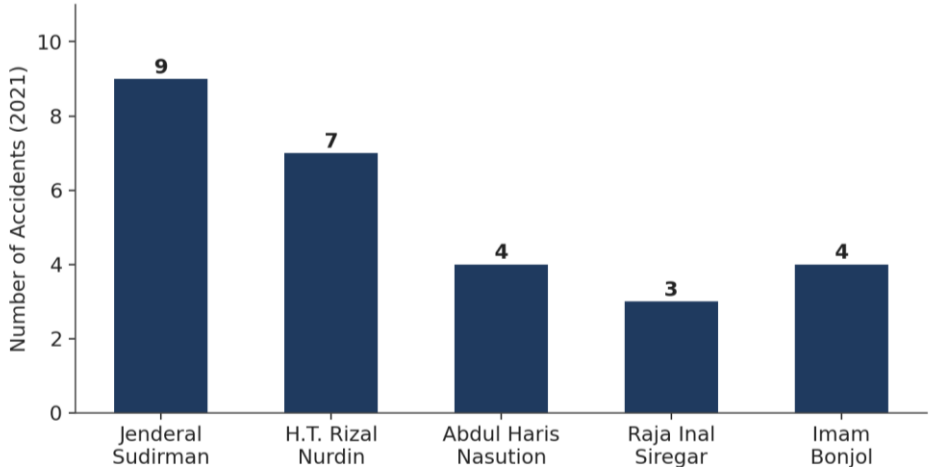

Figure 4. Number of Traffic Accidents by Road Segment, 2021

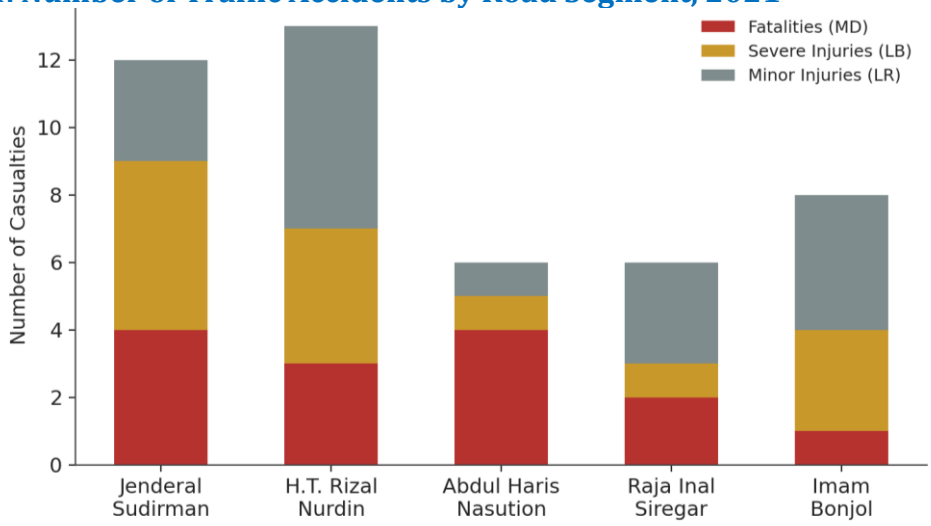

Figure 5. Casualty Severity by Road Segment, 2021

Figure 4 shows that Jenderal Sudirman Road recorded the highest number of events (9 accidents). By month of occurrence, accidents on Jenderal Sudirman Road were concentrated in March and May (2 events each), while by time of day, the 12:01-18:00 window accounted for 4 of the 9 events. By victim age, the 16-50 year age group dominated the casualties.

Figure 5 shows that H.T. Rizal Nurdin Road recorded the highest number of minor-injury casualties among all segments (6 casualties) despite having fewer events than

Jenderal Sudirman Road (7 versus 9), while Abdul Haris Nasution 1 Road recorded 4 fatalities out of 4 events.

d. Collision Diagram Analysis and Dominant Collision Patterns

Collision diagrams were constructed for the priority black-spot road segments in Padangsidimpuan City based on the 2021 traffic accident chronology records. Jenderal Sudirman Road, which recorded the highest weighted black-spot score, was divided into two analysis segments: Segment 1 (STA 0+000–0+350) and Segment 2 (STA 0+350–1+050) to facilitate a more detailed analysis of accident patterns.

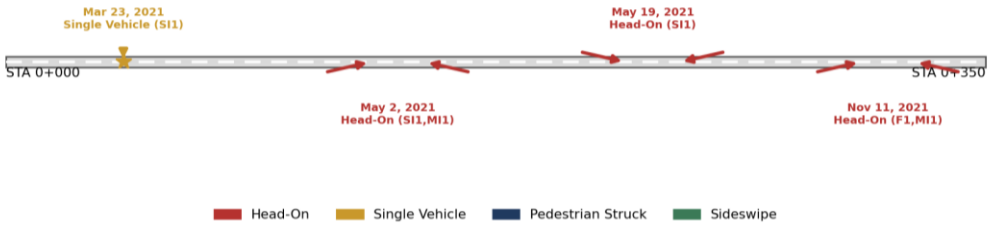

Figure 6. Collision Diagram of Segment 1, Jenderal Sudirman Road (STA 0+000-0+350)

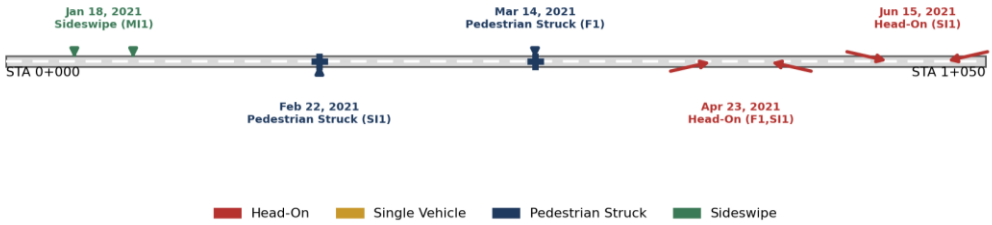

Figure 7. Collision Diagram of Segment 2, Jenderal Sudirman Road (STA 0+350-1+050)

The collision diagram for Segment 1 (Figure 6) shows four accidents during 2021, consisting of one single-vehicle crash caused by a motorcycle striking a pothole and three head-on collisions. The collision diagram for Segment 2 (Figure 7) shows one sideswipe collision, two pedestrian collisions, and two head-on collisions.

Overall, Jenderal Sudirman Road was dominated by head-on collisions, accounting for five of the nine recorded crashes (55.6%), followed by pedestrian collisions (two crashes), single-vehicle crashes (one crash), and sideswipe collisions (one crash).

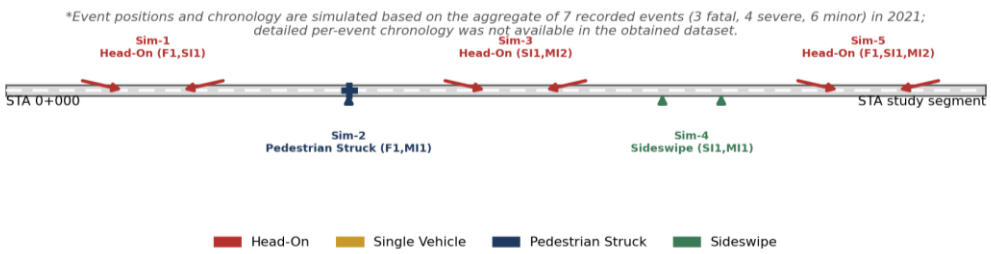

Figure 8. Illustrative Collision Diagram of H.T. Rizal Nurdin Road

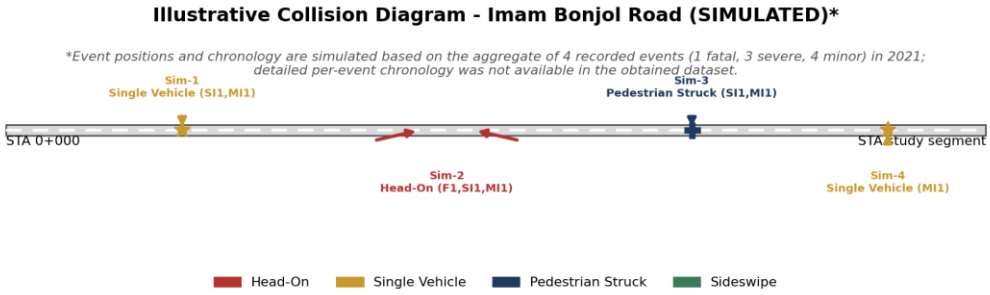

Figure 9. Illustrative Collision Diagram of Imam Bonjol Road

e. Contributing Factor Identification Results

Based on a review of the accident chronology on Jenderal Sudirman Road, contributing factors were grouped into three main aspects, as presented in Table 4.

Tabel 4. Contributing Factors of Traffic Accidents

No	Contributing Factor	Description
1	Human	Physical condition (intoxication, fatigue, illness), driving skill, inattentive pedestrians or crossers, drowsiness, lack of skill, speeding, failure to maintain distance, pedestrian error, animal interference.
2	Vehicle (Means of Transport)	Tire blowout, brake system failure, steering system failure, axle/coupling detachment, lighting system malfunction, engine, brake, tire, and load condition issues.
3	Infrastructure	Intersections, narrow roads, uncontrolled access, unclear or missing road markings, absence of speed-limit signs, slippery road surface, road design (median, gradient, alignment, surface type), traffic control (markings, signs, traffic lights).

Review of the chronology of the 9 accidents on Jenderal Sudirman Road shows a recurring pattern of drivers being careless while overtaking, changing lanes without regard for oncoming traffic, and failing to notice pedestrians. One single-vehicle accident was caused by a pothole in the road surface. A Hazard Identification, Risk Assessment, and Risk Control (HIRARC) analysis on Jenderal Sudirman Road (Maulana, 2022) recorded three risk categories: "Extreme" for high vehicle speeds unmatched by speed-limit signage, "High" for worn-out signage, and "Moderate" for the elevation difference between the road shoulder and the road surface.

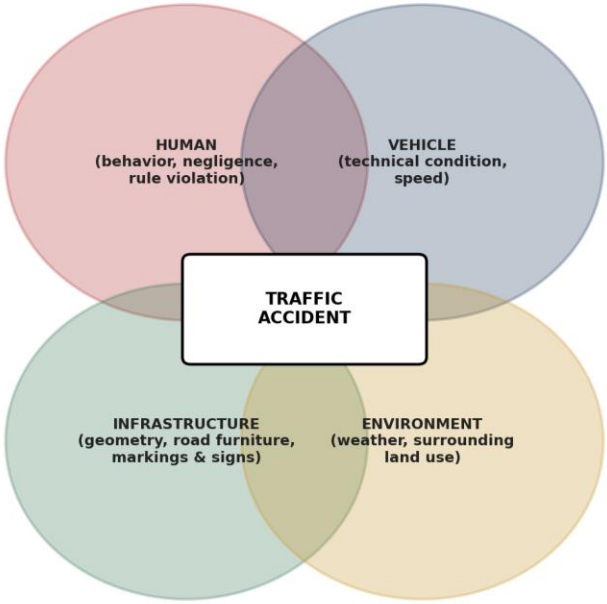

Figure 10. Interrelationship of Traffic Accident Contributing Factors

f. Spatial Distribution of Black Spots

The spatial distribution of the five study road segments in Padangsidimpuan City is presented in **Figure 11**, while the distribution of black-spot locations based on the total weighted accident score is shown in **Figure 12**. The maps were prepared using the Padangsidimpuan road network and the accident data analyzed in this study to illustrate the spatial distribution of the identified black-spot locations.

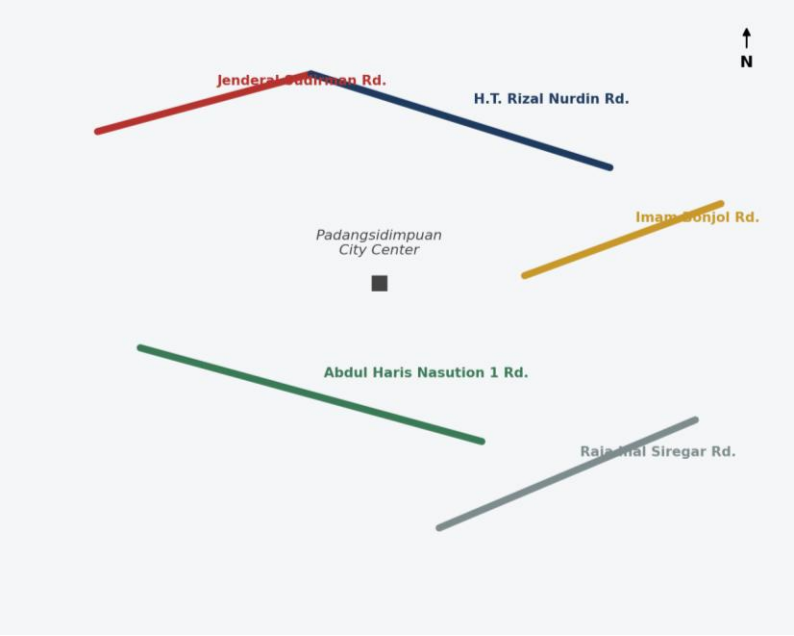

Figure 11. Location Map of the Study Road Segments in Padangsidimpuan City

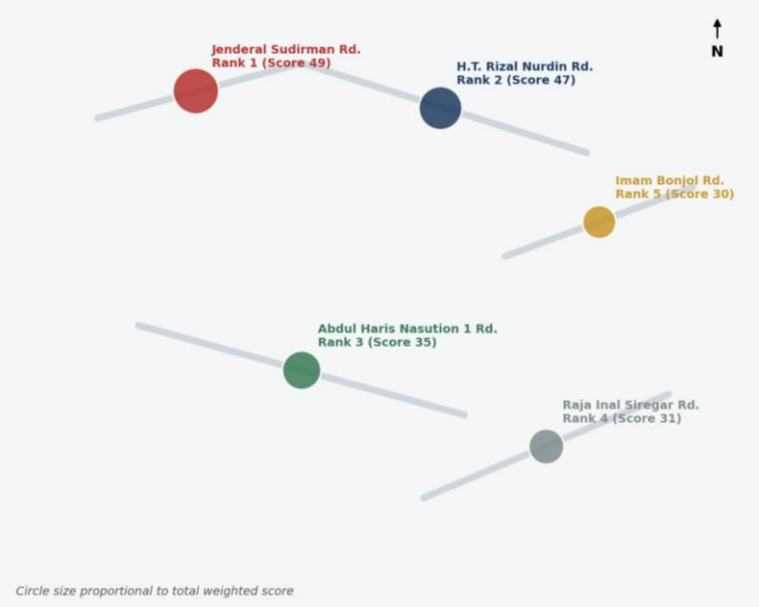

Figure 12. Spatial Distribution of Black Spots in Padangsidimpuan City, 2021

Figure 12 shows that the two road segments with the highest weighted accident scores, Jenderal Sudirman Road and H.T. Rizal Nurdin Road, are located in the northern part of the study area, whereas Abdul Haris Nasution 1 Road is located within a residential area in the southern part of the city. This spatial distribution indicates that the concentration of severe accidents is associated with the functional characteristics of the major arterial corridor, while crashes involving vulnerable road users are more prevalent in residential and school environments.

g. Vehicle Speed Analysis Results

Existing vehicle speeds were obtained through spot-speed surveys and analyzed using the **85th-percentile speed** approach, representing the speed at or below which 85% of observed vehicles travel. The speed analysis results for the priority road segments are presented in **Table 5** and **Figure 13**.

Table 5. 85th-Percentile Vehicle Speed on Priority Road Segments

Road Segment	Data Condition	85th-Percentile Speed (km/h)	Design Speed Limit (km/h)	Category
Jenderal Sudirman Rd.	Inbound direction	57.01	40	Exceeds limit
Jenderal Sudirman Rd.	Outbound direction	55.95	40	Exceeds limit
Abdul Haris Nasution 1 Rd.	Two-direction average	46.01	40–60 (collector); 25 (ZoSS)	Exceeds ZoSS limit
H.T. Rizal Nurdin Rd.	Two-direction average	**51.40**	40–60 (urban arterial)	Exceeds limit

Imam Bonjol Rd.	Recorded maximum speed	84.00	40–60 (urban arterial)	Significantly exceeds limit

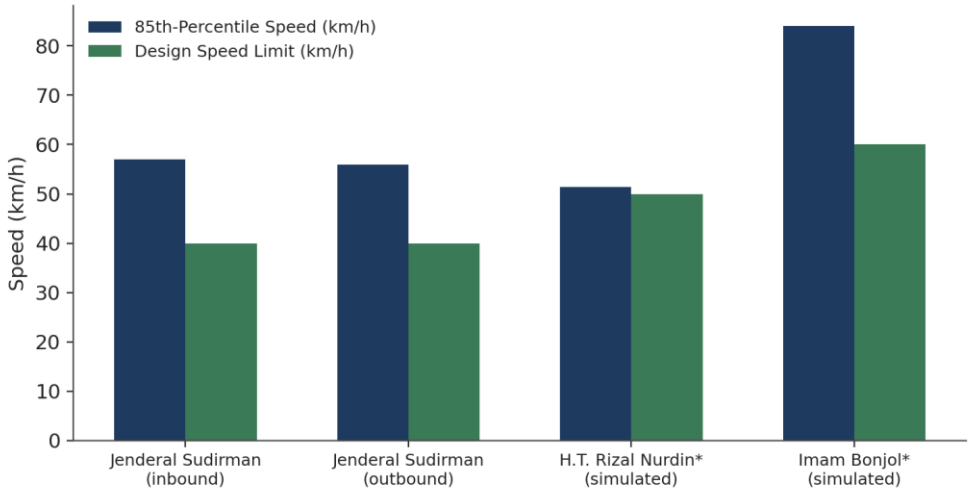

Figure 13. Comparison of 85th-Percentile Motorcycle Speed and Applicable Design Speed Limit

Table 5 and Figure 13 show that vehicle operating speeds on all analyzed road segments exceeded the applicable design or operational speed limits, with the highest speed recorded on **Imam Bonjol Road (84.00 km/h)**. The operating speeds observed on **Jenderal Sudirman Road** also exceeded the design speed limit for an urban collector road, indicating an increased risk of severe collisions, particularly head-on crashes identified in the collision diagram analysis.

On **Abdul Haris Nasution 1 Road**, the average operating speed of **46.01 km/h** exceeded the recommended operational speed for a **School Safety Zone (ZoSS)**. A statistical analysis conducted by **Nauval (2022)** confirmed that the observed speed remained significantly higher than the safe operating speed at the 5% significance level (**Z-calculated = 17.15–18.37 > Z-table**), indicating the need for effective traffic-calming measures and full implementation of ZoSS facilities.

Similarly, the operating speed observed on **H.T. Rizal Nurdin Road** exceeded the recommended speed range for an urban arterial corridor, indicating that speed management measures should also be prioritized on this road segment to reduce the likelihood and severity of traffic accidents

h. Road Geometric Analysis

Geometric analysis was conducted on Jenderal Sudirman Road, the highest-ranked black-spot segment for which complete geometric and traffic data were available. The analysis included stopping sight distance (SSD), horizontal alignment, and road shoulder conditions.

Stopping sight distance analysis, using the observed 85th-percentile operating speed as the representative operating speed, indicated that the available SSD for the inbound

direction was 73.73 m, while the minimum SSD required for a design speed of 40 km/h is 45 m according to AASHTO (1990). For the outbound direction, the available SSD ranged from 71.84 m to 73.54 m, exceeding the minimum design requirement.

Horizontal alignment analysis using the minimum curve-radius equation indicated that an operating speed of 57 km/h requires a minimum horizontal curve radius of 96.17 m, whereas a design speed of 40 km/h requires only 47.36 m. Field measurements showed that the existing curve radius was smaller than the required 96.17 m, indicating that the roadway geometry is inadequate for the observed operating speed and may increase the risk of vehicles losing control while negotiating the curve.

Field observations also showed that the road shoulder consisted of gravelly sand with a noticeable elevation difference relative to the pavement surface. Such conditions may reduce vehicle stability during emergency maneuvers or when drivers leave the travel lane, thereby increasing the likelihood and severity of traffic accidents.

i. Road Furniture Inventory and Traffic Performance Results

An inventory of road safety facilities on Jenderal Sudirman Road indicates the absence of black-spot warning signs and posted speed-limit signs, despite the presence of general warning signs that remain in relatively good condition. The existing pavement markings are generally well maintained; however, the roadway lacks a physical median or continuous centerline markings capable of effectively separating opposing traffic flows.

Traffic performance analysis for Abdul Haris Nasution 1 Road, conducted using the Indonesian Highway Capacity Manual (MKJI, 1997), recorded a traffic volume of 911.1 pcu/h and a roadway capacity of 2,203.70 pcu/h, resulting in a volume-to-capacity (V/C) ratio of 0.41, which corresponds to Level of Service (LOS) B (Nauval, 2022). These results indicate that the roadway continues to operate under stable traffic conditions with sufficient residual capacity.

Considering that Abdul Haris Nasution 1 Road is a 2/2 UD urban collector road located adjacent to a school area, the recommended treatment under the Directorate General of Land Transportation Regulation No. 3582 of 2018 is the implementation of a School Safety Zone (ZoSS) Type 2UD-25. This treatment includes a 25 km/h operational speed limit and a 150 m safety zone, supported by standard facilities such as ZoSS pavement markings, zebra crossings, traffic signs, yellow zigzag markings, and crossing guards, complemented by rumble strips and a warning-light traffic signal (APILL) to improve pedestrian safety, particularly during school arrival and dismissal periods.

j. Comparative Discussion with Prior Studies

The finding of dominant head-on collisions due to the absence of a median on undivided road segments is consistent with the results of similar road safety improvement studies in Jember Regency (Sobirin, 2021), Kampar Regency (Adietya, 2021), and Central Bangka Regency (Muzammil, 2021), all of which similarly identified the combination of high speed and inadequate road furniture as the dominant factor

on inter-city or semi-urban road segments without a median. These three studies, like the present one, employed analyses of accident characteristics, vehicle speed, road geometry, and road furniture, but none integrated a multi-criteria weighting method for city-wide black-spot ranking together with collision diagrams examining specific collision patterns per road segment.

Compared with pedestrian safety and School Safety Zone studies, which are typically conducted separately (Nauval, 2022; Soejachmoen, 2004), this study situates ZoSS requirements within a broader black-spot ranking framework, so that the relationship between accident risk on high-speed through-corridors and pedestrian safety risk in school areas can be viewed as a single, unified urban road safety system, rather than two separate issues. This integrated approach constitutes the primary methodological contribution of this study to the road safety literature in Indonesia, particularly in the context of a mid-sized city such as Padangsidimpuan, which has limited resources to conduct comprehensive road safety audits across all road segments simultaneously.

As a methodological note, the primary limitation of this study is the inconsistent depth of data across road segments-detailed collision diagrams could only be constructed for Jenderal Sudirman Road due to the availability of complete accident chronology documentation, while other segments were analyzed at the annual aggregate level. Future research is recommended to standardize accident chronology recording formats across all road segments in Padangsidimpuan City, so that the collision diagram method can be applied consistently across all black-spot locations identified through weighting.

Discussion

The weighting results in Table 3 show that Jenderal Sudirman Road ranks first with a total score of 49, even though it holds provincial status with collector function, which theoretically carries a lower classification weight than a national arterial road. This position is achieved primarily due to the high casualty severity, namely 4 fatalities out of 9 total accidents, contributing 24 points from the severity criterion alone. This finding indicates that, under the weighting scheme used, casualty severity has a more significant influence on the final ranking than road functional classification alone-a finding relevant for policymakers not to prioritize national arterial roads solely on the basis of classification in road safety programs.

Conversely, Raja Inal Siregar Road, which recorded the highest material loss among the five segments (Rp50,800,000), ranks only fourth because its accident frequency and casualty severity are comparatively lower (3 accidents; 2 fatalities, 1 severe injury, 3 minor injuries). This indicates that large material losses-typically resulting from accidents involving freight or heavily loaded vehicles-are not always linearly correlated with the frequency or severity of casualties, so both dimensions need to be considered separately in formulating handling policy.

Abdul Haris Nasution 1 Road, which in this study serves as comparative data for a school-zone area, ranks third (total score 35) based solely on 2021 accident data. However, Nauval (2022) recorded that over a five-year span (2017-2021) this segment experienced 22 accidents, 10 of which involved school children-a figure not fully reflected in the single-year 2021 weighting. This finding underscores the importance of

considering multi-year historical data as a complement to annual weighting, particularly on road segments with vulnerable user characteristics such as schoolchildren.

Spatially (Figure 12), the two road segments with the highest weighted scores are located on the northern side of the study area, which serves as an inter-regional connecting corridor with high continuous traffic volume, while Abdul Haris Nasution 1 Road is located in a residential area on the southern side. This spatial pattern indicates that road safety prioritization in Padangsidimpuan City needs to differentiate its approach between inter-regional connecting corridors (prone to high-speed collisions) and residential/school-area segments (prone to pedestrian strikes).

The consistent dominance of head-on collisions across both segments of Jenderal Sudirman Road (5 of 9 events, or 55.6%) indicates that the primary contributing factor is systemic across the entire segment: the absence of a median or firm direction-separating markings combined with high vehicle speeds, causing vehicles that lose control or change lanes to directly face opposing traffic. Both pedestrian-struck events on Segment 2 occurred during daytime hours (11:00-15:30 local time) and involved motorcyclists who failed to adequately notice pedestrians, indicating that pedestrian risk on this segment is not confined to the school area alone but also extends to ordinary residential segments.

The HIRARC hazard identification results, which confirm an "Extreme" risk level for high speed unmatched by speed-limit signage, reinforce the conclusion that the interaction between human factors (high speed, negligence) and infrastructure factors (lack of median and signage) is the most influential combination of causes in the accident pattern on this segment, consistent with the principle that accidents are rarely caused by a single factor alone, but rather by the interaction of at least two mutually reinforcing factors (Hobbs, 1979, as cited in Azizirrahman et al., 2015).

The collision diagrams of H.T. Rizal Nurdin Road and Imam Bonjol Road reveal traffic accident characteristics comparable to those observed on Jenderal Sudirman Road. Head-on collisions remain the predominant crash type on the arterial road segments, while pedestrian collisions occur primarily in locations with higher roadside activities. These findings are consistent with previous road safety studies in Indonesia, which reported that head-on collisions are the dominant crash type on undivided arterial roads lacking physical median separation (Sugiyanto & Mina, 2015).

The 85th-percentile motorcycle speed on Jenderal Sudirman Road, reaching 57.01 km/h inbound-42.5% higher than the 40 km/h design speed limit-directly contributes to the dominance of head-on collisions identified in the collision diagrams, because at higher speeds, drivers have a shorter reaction time and a longer braking distance to avoid a collision when facing oncoming traffic.

The most extreme case was recorded on Imam Bonjol Road, with a maximum motorcycle speed of 84 km/h, twice the typical design speed limit for an urban arterial road. Such a speed on a segment that also serves residential activity and pedestrian crossings has the potential to produce severe accident outcomes in the event of a collision with a pedestrian, given that pedestrian fatality risk increases sharply at impact speeds above 50 km/h based on various international road safety studies.

The field-measured curve radius on Jenderal Sudirman Road, which does not meet the 96.17 m minimum radius required based on actual speed, indicates a mismatch between the road's geometric design and the actual speed behavior of road users-a condition that contradicts the principle of a self-explaining road, whereby road geometry should naturally "guide" drivers toward selecting a speed appropriate to the segment's characteristics (Murjanto, 2012). The gravelly-sand road shoulder with an elevation difference constitutes an additional risk factor, as it has the potential to cause loss of vehicle control-particularly for motorcycles-when a vehicle exits the travel lane, as identified in the single-vehicle accident on Segment 1.

The V/C ratio of 0.41 with LOS B on Abdul Haris Nasution 1 Road indicates that traffic flow remains stable with drivers retaining relatively high freedom to select their speed-a condition that paradoxically increases risk for pedestrians due to the lack of natural constraints on vehicle speed. Although the average recorded speed of 46.01 km/h still falls within the collector-class design speed range (40-60 km/h), this value far exceeds the 25 km/h speed limit recommended for a School Safety Zone. The Z-statistical test result confirming that the speed in front of the school is not yet "safe" at the 5% error level reinforces the urgency of implementing a 2UD-25 type ZoSS on this segment as part of the city's overall road safety system, rather than merely a localized requirement at a single school location.

The finding of dominant head-on collisions due to the absence of a median on undivided road segments is consistent with the results of similar road safety improvement studies in Jember Regency (Sobirin, 2021), Kampar Regency (Adietya, 2021), and Central Bangka Regency (Muzammil, 2021), all of which similarly identified the combination of high speed and inadequate road furniture as the dominant factor on inter-city or semi-urban road segments without a median. These three studies, like the present one, employed analyses of accident characteristics, vehicle speed, road geometry, and road furniture, but none integrated a multi-criteria weighting method for city-wide black-spot ranking together with collision diagrams examining specific collision patterns per road segment.

Compared with pedestrian safety and School Safety Zone studies, which are typically conducted separately (Nauval, 2022; Soejachmoen, 2004), this study situates ZoSS requirements within a broader black-spot ranking framework, so that the relationship between accident risk on high-speed through-corridors and pedestrian safety risk in school areas can be viewed as a single, unified urban road safety system, rather than two separate issues. This integrated approach constitutes the primary methodological contribution of this study to the road safety literature in Indonesia, particularly in the context of a mid-sized city such as Padangsidimpuan, which has limited resources to conduct comprehensive road safety audits across all road segments simultaneously.

Although accident chronology data were available for all analyzed road segments, differences in accident frequency and roadway characteristics resulted in varying levels of detail in the collision diagrams. Future studies are encouraged to expand the analysis period and integrate Geographic Information System (GIS)-based accident databases to improve the spatial accuracy and long-term monitoring of black-spot locations.

Based on the overall results and discussion of collision diagrams, contributing factors, speed, and road geometry, handling recommendations were formulated specifically for each road segment according to its dominant collision pattern, as presented in Table 6.

Tabel 6. Handling Recommendations for Accident-Prone Areas Based on Dominant Collision Patterns

Table 6. Handling Recommendations for Accident-Prone Areas Based on Dominant Collision Patterns

Road Segment	Dominant Collision Pattern	Recommended Countermeasures
Jenderal Sudirman Road	Head-on (55.6%), pedestrian collisions, single-vehicle crashes	Install a 40 km/h speed limit sign; provide black-spot warning signs approximately 50 m before hazardous locations; install rumble strips on both segments; evaluate the construction of a raised median or double solid centerline; repair pavement defects and improve road shoulders.
H.T. Rizal Nurdin Road	Head-on collisions and pedestrian collisions	Install warning signs and clear pavement markings; improve street lighting (PJU); implement speed management measures; provide pedestrian crossing facilities where pedestrian activity is high; conduct periodic road safety monitoring.
Imam Bonjol Road	High-speed motorcycle crashes	Install highly visible speed limit signs; provide rumble strips; strengthen speed enforcement by the traffic police; improve driver safety awareness through road safety campaigns.
Abdul Haris Nasution 1 Road	Pedestrian collisions involving school children	Implement a School Safety Zone (ZoSS) Type 2UD-25 over approximately 150 m; install zebra crossings, yellow zig-zag pavement markings, ZoSS warning signs, crossing guards, additional sidewalks, rumble strips, and warning flash signals (APILL warning lights).
Raja Inal Siregar Road	Material-loss crashes and heavy-vehicle-related accidents	Improve traffic management for heavy vehicles; install appropriate warning signs and pavement markings; evaluate roadside conditions and access management; enhance road safety facilities based on the identified collision characteristics.

Table 6 confirms that handling recommendations cannot be uniform across all road segments but must instead be tailored to the dominant collision pattern identified through the collision diagram. Segments with a dominant head-on collision pattern require intervention in direction separation and speed control, while segments with a dominant pedestrian-struck pattern require intervention in pedestrian and crossing facilities, as reflected in the fundamental difference between the recommendations for Jenderal Sudirman Road and Abdul Haris Nasution 1 Road.

For the Padangsidimpuan City Government, the black-spot weighting and ranking results from this study can serve as a basis for prioritizing the annual road safety budget, particularly for prioritizing Jenderal Sudirman Road and H.T. Rizal Nurdin Road as the two segments with the highest weighted scores, without neglecting the urgent need for

School Safety Zone implementation on Abdul Haris Nasution 1 Road, given the involvement of schoolchildren as a vulnerable road-user group.

For the Transportation Agency, the collision diagram method used in this study can be adopted as a standard instrument in periodic road safety audits, so that the type and location of road furniture-such as signs, markings, and rumble strips-can be tailored to the specific collision pattern on each segment, rather than following a generic approach. The Transportation Agency should also prioritize installing speed-limit signs and black-spot warning signs on segments identified as lacking such furniture.

For the Police, particularly the Traffic Unit, the finding that vehicle speeds consistently exceed the design speed limit on all analyzed segments indicates the need for increased speed-enforcement intensity, particularly during peak accident hours (12:01-18:00 in the case of Jenderal Sudirman Road). Continuous updating and standardization of the accident chronology database across all road segments are recommended to support long-term road safety monitoring and future collision-diagram analyses.

For the National and Provincial Road Authorities, the geometric analysis findings-showing a mismatch between the existing curve radius and actual vehicle speed on Jenderal Sudirman Road-should inform road maintenance and improvement planning, including consideration of median or firm direction-separating markings on segments with a high history of head-on collisions.

For future research, this study recommends three directions for development. First, future studies should expand the analysis period by incorporating multi-year accident records to evaluate temporal changes in black-spot characteristics. Second, expansion of black-spot weighting coverage to all 34 road segments in Padangsidimpuan City, not limited to the five segments with the highest scores, to obtain a more comprehensive city road safety map. Third, a before-after evaluation study of the effectiveness of implemented handling recommendations, particularly the reduction in vehicle speed and number of accidents following the installation of signs, markings, and rumble strips, as a follow-up to the descriptive study conducted in this research.

4. CONCLUSIONS AND SUGGESTIONS

This study identified accident-prone road segments in Padangsidimpuan City using a multi-criteria weighting method. Jenderal Sudirman Road ranked as the highest-priority black spot (score = 49), followed by H.T. Rizal Nurdin Road (47), Abdul Haris Nasution 1 Road (35), Raja Inal Siregar Road (31), and Imam Bonjol Road (30), indicating that casualty severity contributed more strongly to the ranking than road classification.

Collision diagram analysis revealed that head-on collisions were the dominant crash pattern on Jenderal Sudirman Road (55.6%), primarily associated with excessive vehicle speed, driver negligence, the absence of a median, inadequate road signage, and poor shoulder conditions. Speed and geometric analyses further showed that operating speeds on the analyzed road segments exceeded the applicable design limits, while the existing roadway geometry did not fully accommodate actual driving speeds.

Based on these findings, countermeasures were proposed according to the dominant collision patterns on each road segment, including speed management, installation of

warning signs and rumble strips, median or centerline improvements, and implementation of a School Safety Zone (ZoSS) on Abdul Haris Nasution 1 Road. These findings provide practical guidance for prioritizing road safety improvements in Padangsidimpuan City and support data-driven decision-making for future traffic safety programs.

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