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Risk-Based Prioritization of School Safety Zone Interventions Based on Accident Risk and Safety Facility Conditions in Banjar City

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ABSTRACT

This study examined seven School Safety Zones (ZoSS) in Banjar City, West Java, where traffic conditions and safety facilities vary across schools. It aimed to assess traffic conditions and facility compliance, rank schools needing safety improvements, and propose interventions with cost estimates. A quantitative approach was used, combining traffic surveys, vehicle speed measurements, inspections of 18 safety facility components, student enrollment data, and distances to accident-prone areas. Six indicators—traffic volume, degree of saturation, vehicle speed, number of students, facility deficiencies, and distance to accident-prone areas—were assessed using the Weighted Linear Combination (WLC) method. Traffic volumes ranged from 177 to 502 vehicles per hour, while vehicle speeds ranged from 37.5 to 43 km/h. None of the assessed safety facility components at SDN 3 Mulyasari and MI Rancakole met the requirements. Facility deficiencies reached 83.3% at SDN 1 Karangpanimbal and SDN 1 Sukamukti. Based on the reported WLC rankings, SDN 1 Karangpanimbal was the first priority (score 106), followed by SDN 7–9 Hegarsari (138) and SDN 1 Sukamukti (190). Proposed interventions include warning lights, traffic signs, road markings, and other supporting safety facilities. The estimated total cost for these three locations is IDR 469,047,563.33, potentially benefiting 607 students. The findings provide local authorities with an initial basis for selecting intervention sites, identifying needed facilities, and planning safety budgets. However, inconsistencies in facility deficiency data across tables and incomplete WLC weighting details must be resolved before the rankings guide final funding decisions. Because the proposed improvements have not yet been implemented, their effects on traffic speeds, pedestrian safety, and crashes remain untested. Future evaluations should assess actual conditions after installation to establish whether the interventions improve student safety. the tudy connects field assessments with practical planning while recognizing that stronger evidence and verified calculations are necessary for reliable implementation decisions.

Keywords: *School Safety Zones, Road Safety, Accident Risk, Weighted Linear Combination, Repair Priorities.*

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INTRODUCTION

Child safety on the roads remains a critical issue in many countries, including Indonesia. Every day, children must cross roads used by various types of vehicles on their way to and from school. This situation can put them at risk, especially when vehicles are traveling at high speeds and pedestrian crossings are inadequate. According to the World Health Organization (WHO) [1], traffic accidents cause approximately 1.19 million deaths worldwide each year and are the leading cause of death among people aged 5–29. This issue underscores the need for serious attention to be paid to the safety of the commute to school. One initiative implemented in Indonesia is the School Safety Zone (ZoSS), which consists of road areas around schools equipped with facilities to help protect students from traffic hazards. However, the presence of a ZoSS does not necessarily guarantee safety if the facilities are incomplete, do not meet requirements, or are not suited to traffic conditions.

This problem was also found in school zones in Banjar City, West Java. Based on survey data from this study, seven school zones were observed along four road segments: Jalan Siliwangi III, Jalan Raya Batulawang II, Jalan Raya

Batulawang IV, and Jalan Langensari VII. Traffic volume on these segments ranged from 177 to 502 passenger vehicles per hour, with vehicle speeds ranging from 37.5 to 43 km/h. An inspection of 18 safety facility components in each zone revealed that SDN 3 Mulyasari and MI Rancakole had all assessed components rated as non-compliant. Meanwhile, SDN 1 Karangpanimbal and SDN 1 Sukamukti had a facility deficiency rate of 83.3%. Furthermore, SDN 1 Karangpanimbal is located in an area that has been identified as accident-prone. These differing conditions indicate that each school's safety needs are not the same. Therefore, an assessment is needed to help the government determine which schools should be addressed first, especially when the budget for repairs is limited.

Research on school zone safety has expanded in recent years. [2] conducted a systematic review of 53 studies on child safety in school zones. They demonstrated that child safety is influenced by road user behavior, traffic characteristics, environmental conditions, and the availability of safety facilities. These findings are consistent with those of [3], who explained that children's travel safety is not only related to the physical condition of the road but also to how children interact with the traffic environment. Both studies provide a strong foundation for understanding the various factors that influence children's safety. However, the discussion of these risk factors has not yet directly provided a simple way to compare improvement needs across schools with different conditions.

Other studies have sought to assess school safety through direct observation of vehicles and pedestrians. Renard et al. [4] used drone footage to identify potential traffic conflicts around elementary schools in Zagreb, Croatia, and identified 43 incidents with the potential to cause accidents. Meanwhile, [5] investigated conflicts between vehicles and pedestrians in school zones in Ghana, Vietnam, and Mexico. They found that safety improvements can reduce the number of observed traffic conflicts. Both studies highlight the importance of measuring real-world conditions on the road. However, their primary focus is on identifying conflicts and evaluating safety measures at the observed locations rather than establishing a priority order for improvements across multiple schools based on a combination of traffic conditions, infrastructure, and budgetary needs.

Another approach was taken by [6] in South Korea, who used video processing and deep learning technologies to assess changes in safety following the implementation of school zone policies. The study showed a decrease in vehicle speed and an improvement in drivers' behavior in yielding to pedestrians. These results reinforce the view that school safety should be assessed based on actual traffic conditions, not merely on the presence of signs and markings. However, this approach focuses more on evaluating the impact of policies that have already been implemented. For local governments that still need to select locations for improvements, a different approach is needed that can be used before safety facilities are constructed.

The prioritization of school safety has also been studied using data-driven approaches and multi-criteria decision-making. [7] developed a data-driven framework to prioritize Safe Routes to School programs by analyzing approximately 3,000 schools in Florida, United States. The study used road, environmental, and population characteristics to identify factors associated with pedestrian and cyclist accidents. On the other hand, [8]used the Analytic Hierarchy Process (AHP) method to prioritize school safety issues based on parents' concerns, including traffic density and vehicle arrangements when dropping off students. Both studies demonstrate that prioritizing school safety can be done systematically. However, their assessment indicators and objectives differ. Lee et al. placed greater emphasis on modeling accident factors and planning safety programs, whereas Salleh focused more on priority assessment based on parental considerations. Neither study specifically addressed the need to evaluate the seven ZoSS in Banjar City using the six technical indicators available in this study or linked the ranking results to facility design and cost estimates.

Based on previous research, the research gap lies in the need for a simple, measurable ZoSS prioritization framework that is aligned with the availability of data at the local government level. Previous studies have provided evidence regarding risk factors, the potential for conflicts between vehicles and pedestrians, the effectiveness of safety policies, and the use of decision-making methods. However, these studies have different focuses and types of data. There remains a need for an approach that collectively considers traffic volume, congestion levels, vehicle speeds, the number of students, deficiencies in safety facilities, and distance to accident-prone areas to compare the management needs across school zones within the context of Banjar City. Furthermore, the assessment results must be linked to facility needs and budget estimates so they can inform development decisions, rather than merely serving as an assessment of safety conditions.

The novelty of this study lies in the integration of six safety indicators into a single framework for prioritizing ZoSS interventions, linked to management recommendations and cost estimates at the school-site level. The study uses the Weighted Linear Combination (WLC) method to combine indicators with different units into a comparable assessment score. While the WLC method is not new, its application in this study is specifically aimed at addressing decision-

making needs across seven school zones with distinct characteristics. This approach not only considers schools located near accident-prone areas but also takes into account traffic conditions, student enrollment, and facility deficiencies identified in the field. Consequently, the assessment results can serve as a basis for selecting intervention sites and formulating improvement proposals tailored to the needs of each school.

This study aims to: evaluate traffic conditions and the adequacy of safety facilities in seven school zones in the city of Banjar; determine the priority order for School Zone Safety (ZoSS) interventions using the WLC method based on six indicators: traffic volume, degree of saturation, vehicle speed, number of students, lack of safety facilities, and distance to accident-prone areas; and formulate recommendations for improving safety facilities and calculate estimated budget requirements for the three locations identified as priorities for intervention. Through these objectives, the study is expected to produce assessments that are traceable and comparable across locations.

The contributions of this study encompass methodological, empirical, and practical aspects. From a methodological perspective, the study provides a method for combining six safety indicators to serve as a basis for comparing intervention needs across schools. From an empirical perspective, the study presents information on differences in traffic conditions, student enrollment, and safety facilities across seven school zones in the city of Banjar. From a practical perspective, the study provides a basis for the Department of Transportation and local governments to determine the order of priority for addressing issues, select the types of facilities that need improvement, and estimate the required budget. The study's findings are expected to facilitate a more targeted use of road safety budgets, so that locations requiring attention can be identified based on clear assessment results, rather than solely on estimates or the number of available facilities.

METHOD

Research Design and Study Location

This study used a descriptive-evaluative quantitative approach to assess the safety conditions of School Safety Zones (ZoSS) and determine intervention priorities based on traffic characteristics, safety facility conditions, student exposure, and proximity to accident-prone areas. The study was conducted in seven school zones spread across four road sections in the city of Banjar: Jalan Siliwangi III, Jalan Raya Batulawang II, Jalan Raya Batulawang IV, and Jalan Langensari VII. Each school zone served as a unit of analysis, including the group comprising SDN 7–9 Hegarsari, which was assessed as a single zone.

Data Collection and Research Variables

The research data consists of primary and secondary data. Primary data was obtained through surveys of traffic volume, vehicle speed, road geometry, and an inventory of safety facilities [9], [10]. Secondary data includes the number of students, information on accident-prone areas, and supporting data from relevant agencies [11].

The analysis used six indicators: traffic volume (Q), degree of saturation (DJ), travel speed (V), number of students (N), percentage of safety facility deficiencies (G), and distance from the school to accident-prone areas (D). These six indicators were selected to represent traffic operational conditions, students' potential exposure to risk, deficiencies in safety infrastructure, and proximity to accident locations [12].

Analysis of Traffic Conditions and Safety Facilities

Traffic performance was analyzed using vehicle volume, road capacity, and travel speed. The degree of saturation was calculated based on the 2023 Indonesian Road Capacity Guidelines (PKJI) using the following equation [13], [14]:

$$DJ = \frac{Q}{C} \tag{1}$$

where Q represents traffic volume (vehicles per hour) and C represents road capacity (vehicles per hour).

The evaluation of safety facilities is conducted by comparing existing conditions against applicable technical requirements. The facilities inspected include traffic signs, road markings, crosswalk facilities, warning devices, and other supporting facilities. The percentage of facility deficiencies is calculated using the equation [15], [16]:

$$G = \left(\frac{n_t}{n_p}\right) \times 100\% \tag{2}$$

where n_t is the number of facilities that do not meet the requirements and n_p is the total number of facilities assessed. Based on the research inventory, there are 18 facility items in each school zone. The higher the value of G, the greater the need for safety facility improvements.

Prioritization Using the Weighted Linear Combination Method

Intervention priorities were determined using the Weighted Linear Combination (WLC) method, which involves combining six indicators through normalization and weighting. Min–max normalization was used to standardize the indicator scales so that each variable could be compared [17], [18].

To establish a safety score where lower values indicate a greater need for intervention, the indicators of traffic volume, degree of saturation, speed, number of students, and lack of facilities are normalized using [19], [20]:

$$s_{ij} = \frac{x_{max,j} - x_{ij}}{x_{max,j} - x_{min,j}} \tag{3}$$

Meanwhile, the distance-to-accident-prone-area indicator is normalized using:

$$s_{ij} = \frac{x_{ij} - x_{min,j}}{x_{max,j} - x_{min,j}} \tag{4}$$

If the maximum and minimum values are the same, the indicator is assigned the same neutral value for all locations so as not to affect the ranking order.

The composite score is calculated using the following equation [21], [22]:

$$S_i = \sum_{j=1}^{6} (w_j \times s_{ij}) \tag{5}$$

where S_i is the composite safety score for the i-th school zone, w_j is the weight of the j-th indicator, and s_{ij} is the normalized value. The sum of all weights is set to one ($\Sigma w_j = 1$). Weights must be determined based on a documented procedure and applied consistently across all locations [23], [24].

School zones were ranked based on their composite scores, from lowest to highest. Lower scores indicate a greater need for intervention. The three locations with the highest priority were selected for the development of intervention recommendations.

Development of Interventions and Cost Estimates

Intervention recommendations were developed based on the WLC ranking results, safety facility deficiencies, road characteristics, and the specific needs of each location. Interventions include the addition or repair of traffic signs, warning lights, thermoplastic and cold plastic markings, as well as supporting safety facilities in accordance with location-specific needs and technical requirements [25], [26].

Cost estimates are calculated using the quantity-and-unit-price approach. Total direct costs are calculated using the following equation [12]:

$$B = \sum_{k=1}^{m} (q_k \times h_k) \tag{6}$$

where B is the estimated direct cost, q_k is the volume of the k-th type of work, h_k is the unit price, and m is the number of work types. Indirect costs and taxes are added if applicable and not already included in the unit price [27], [28], [29]. This estimate is used as the basis for initial planning of the intervention's budget requirements, not as the final construction cost.

Data Analysis Framework and Research Ethics

The analytical framework comprised six stages: traffic assessment, safety facility assessment, crash risk assessment, exposure assessment, WLC-based prioritization, and intervention development with preliminary cost estimation. The results were integrated to rank schools and identify site-specific safety improvements [17]. Transparency and reproducibility were ensured through documented assessment criteria, normalization procedures, weightings, rankings, intervention quantities, and cost sources. Institutional permission was obtained where required for access to restricted data. Relevant research ethics approval or exemption was reported when applicable, based on the actual study procedures and journal requirements [30]. The study outputs included traffic and safety assessments, a facility compliance matrix, exposure and crash risk evaluations, school priority rankings, targeted intervention recommendations, and preliminary cost estimates [4].

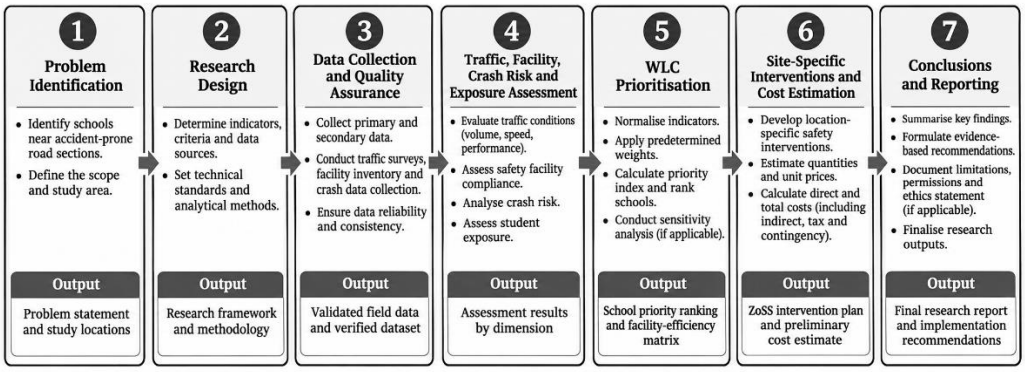


Figure 1. Research Methodology for School Safe Zone Design (ZoSS)

RESULTS

An inventory of existing safety facilities was conducted to assess the extent to which school-zone infrastructure meets the requirements for implementing the School Safe Zone (ZoSS) in Banjar City. The assessment covered the availability of ZoSS signs, crossing warning signs, speed limit signs, crossing location signs, red pavement markings, rumble strips, and other supporting safety facilities. The inventory results were categorized based on the number of facilities that met and did not meet the requirements, as shown in Table 1.

Table 1. Conditions of Existing Safety Facilities in the Surveyed School Zones

School zone	Facilities meeting requirements (n)	Facilities not meeting requirements (n)	Available (%)	Not available (%)
SDN 1 Raharja	10	8	55.6	44.4
Raharja Elementary School No. 2	14	4	77.8	22.2
Karangpanimbal Elementary School No. 1	3	15	16.7	83.3
Hegarsari Elementary Schools 7–9	16	2	88.9	11.1
Sukamukti Elementary School No. 1	3	15	16.7	83.3
Mulyasari Elementary School No. 3	0	18	0.0	100.0
Rancakole Islamic Elementary School	0	18	0.0	100.0

The inventory suggests that facility provision should be assessed as a coordinated system rather than as isolated signs or markings. For example, signs without clearly marked crossing areas may not adequately guide students, while crossing facilities on roads with relatively high vehicle speeds may require complementary speed-management measures. The facility inventory is therefore considered alongside traffic conditions and school exposure in the priority assessment.

Traffic Characteristics of School-Zone Road Segments

Traffic volume across the surveyed road segments ranged from 177 to 502 passenger-car units per hour (pcu/h). Jalan Raya Batulawang II, serving SDN 7, SDN 8, and SDN 9 Hegarsari, recorded the highest traffic volume (502 pcu/h). Jalan Langensari VII, serving SDN 3 Mulyasari and MI Rancakole, recorded the lowest volume (177 pcu/h). The road-segment characteristics are presented in Table 2.

Table 2. Traffic Characteristics of School-Zone Road Segments

School(s) Served	Road segment	Road type	Volume (vehicles per hour)	Capacity (pcu/h)	Degree of saturation	Free-flow speed (km/h)	Travel speed (km/h)	Density (pcu/km)
Raharja Elementary School No. 1; Raharja Elementary School No. 2; Karangpanimbal Elementary School No. 1	Siliwangi III Road	2/2 undivided	273	2700.43	0.10	41.96	41.5	6.58

Hegarsari Elementary School 7–9	Batulawang II Highway	4/2 undivided	502	2646.29	0.19	44.66	43.0	11.67
SDN 1 Sukamukti	Batulawang IV Highway	2/2 undivided	431	2,520.00	0.17	40.92	39.5	10.91
Mulyasari Elementary School No. 3; Rancakole Islamic Elementary School	Langensari VII Street	2/2 undivided	177	January 2017	0.09	36.60	37.5	4.72

Jalan Raya Batulawang II recorded the highest traffic volume, degree of saturation, free-flow speed, travel speed, and traffic density among the listed segments. Jalan Langensari VII recorded the lowest traffic volume, degree of saturation, and density. These differences indicate that the school zones are exposed to different traffic environments and should not be treated as having identical safety needs.

Indicator Normalization and Weighted Linear Combination

The prioritization of School Safe Zone (ZoSS) interventions was based on six indicators: traffic volume, degree of saturation, travel speed, student population, facility gaps, and distance to an identified high-risk area. These indicators represent different dimensions of school zone risk, including traffic conditions, potential student exposure, infrastructure deficiencies, and proximity to locations with a history of traffic accidents. Because the indicators are measured using different units and scales, normalization is required before they can be combined using the Weighted Linear Combination (WLC) method.

The WLC approach combines normalized indicator values with their corresponding weights to produce a composite priority index for each school zone. In this study, the reported scoring convention indicates that a lower total score corresponds to a higher intervention priority. The resulting priority index is therefore interpreted according to the scoring convention used in the source data, rather than assuming that a higher composite score necessarily represents greater risk.

To ensure reproducibility, the normalization procedure should specify the original value of each indicator, its normalization formula, the resulting normalized score, the assigned weight, and the weighted contribution. However, the available data do not provide the complete normalization calculations or the individual indicator weights. Consequently, the reported priority scores are retained as provided, while the numerical derivation of the WLC index remains subject to verification.

WLC Priority Index and Ranking

Table 3. WLC-Based Priority Ranking of School-Zone Interventions

Priority rank	School zone	Road segment	Traffic volume (pcu/h)	Degree of saturation	Travel speed (km/h)	Students (n)	Facility gap (%)	Distance to black area (km)	Total score
1	SDN 1 Karangpanimbal	Siliwangi III Street	273	0.10	41.5	127	15.8	0.0	106
2	Hegarsari Elementary Schools 7–9	Batulawang II Highway	502	0.19	43.0	287	84.2	1.4	138
3	SDN 1 Sukamukti	Batulawang IV Highway	431	0.17	39.5	193	15.8	1.2	190
4	MI Rancakole	Langensari VII Street	177	0.09	37.5	109	0.0	2.6	200
5	Raharja Elementary School No. 2	Siliwangi III Street	273	0.10	41.5	122	73.7	1.9	240
6	Raharja Elementary School No. 1	Siliwangi III Street	273	0.10	41.5	191	52.6	2.2	363
7	Mulyasari Elementary School No. 3	Langensari VII Street	177	0.09	37.5	121	0.0	1.2	439

The WLC-based ranking places SDN 1 Karangpanimbal as the top priority, with a total score of 106, followed by SDN 7–9 Hegarsari with a score of 138 and SDN 1 Sukamukti with a score of 190. MI Rancakole ranks fourth with a score

of 200, followed by SDN 2 Raharja with a score of 240, SDN 1 Raharja with a score of 363, and SDN 3 Mulyasari with a score of 439. In accordance with the scoring convention reported for this study, a lower score indicates a higher priority for intervention.

SDN 1 Karangpanimbal is ranked first and is located 0.0 km from, or directly within, the identified black area. The site has a recorded traffic volume of 273 pcu/h, a degree of saturation of 0.10, a travel speed of 41.5 km/h, and 127 students. Its reported facility gap is 15.8%. The combination of its location within a "black area" and school-related exposure supports its position as the highest-priority location in the reported ranking. This result indicates that the prioritization takes into account more than just traffic volume, including the site's proximity to an identified accident-prone area.

SDN 7–9 Hegarsari ranks second, with a total score of 138. It has the highest traffic volume among the seven school zones, at 502 pcu/h, and the largest student population, at 287. Its degree of saturation is 0.19, its travel speed is 43.0 km/h, and its distance to the identified black area is 1.4 km. The reported facility gap is 84.2%. These characteristics indicate that Hegarsari has substantial traffic activity and student exposure, along with a considerable reported facility gap. The proposed intervention should therefore address the condition and visibility of school zone safety facilities, subject to verification of the facility inventory.

SDN 1 Sukamukti ranks third, with a total score of 190. The site records a traffic volume of 431 pcu/h, a degree of saturation of 0.17, a travel speed of 39.5 km/h, and 193 students. Its reported facility gap is 15.8%, and its distance to the identified black area is 1.2 km. These figures indicate that Sukamukti combines a relatively high traffic volume with a substantial student population. Its third-place ranking supports its inclusion among the locations requiring priority consideration for safety improvements.

MI Rancakole ranks fourth, with a total score of 200. The recorded traffic volume is 177 vehicles per hour, the degree of saturation is 0.09, and the travel speed is 37.5 km/h. The site has 109 students, a reported facility gap of 0.0%, and is 2.6 km from the identified black area. Although its traffic indicators are lower than those recorded at Hegarsari and Sukamukti, the ranking places MI Rancakole fourth based on the reported WLC results. Its facility gap value should be verified against the original inventory before drawing conclusions about the adequacy of its existing safety facilities.

SDN 2 Raharja ranks fifth, with a total score of 240. Its recorded traffic volume is 273 pcu/h, the degree of saturation is 0.10, and the travel speed is 41.5 km/h. The school has 122 students, a reported facility gap of 73.7%, and is located 1.9 km from the identified black area. The reported facility gap indicates a potential need to examine the condition and assess al compliance of the existing facilities. However, the specific facilities requiring improvement should be determined through verification of the site inventory.

SDN 1 Raharja ranks sixth, with a total score of 363. The recorded traffic volume is 273 pcu/h, the degree of saturation is 0.10, and the travel speed is 41.5 km/h. The site has 191 students, a reported facility gap of 52.6%, and a distance of 2.2 km to the identified black area. Although SDN 1 Raharja has more students than SDN 1 Karangpanimbal and SDN 2 Raharja, it ranks sixth in the reported WLC results. This discrepancy underscores the importance of interpreting the ranking based on the combined indicators rather than student population alone.

SDN 3 Mulyasari ranks seventh, with a total score of 439. The site records a traffic volume of 177 pcu/h, a degree of saturation of 0.09, a travel speed of 37.5 km/h, and 121 students. Its reported facility gap is 0.0%, and its distance to the identified black area is 1.2 km. Although the reported traffic volume and travel speed are lower than those at several higher-ranked sites, its seventh-place ranking aligns with the total score and ranking presented in Table 4. The facility gap value should be verified against the original inventory before the condition of its existing facilities is interpreted.

Overall, the reported WLC ranking identifies SDN 1 Karangpanimbal, SDN 7–9 Hegarsari, and SDN 1 Sukamukti as the three highest-priority locations. The seven school zones differ in traffic volume, saturation, travel speed, student population, facility gap, and distance to the identified black area. The ranking provides a basis for prioritizing interventions; however, the normalization formulas and indicator weights should be documented to allow for independent reproduction of the reported scores.

Site-Specific Intervention Design and Estimated Costs

Interventions for the three highest-priority locations are proposed based on student exposure, road and traffic characteristics, and proximity to accident-prone areas. Tables describing the priority schools and proposed interventions have been consolidated into a single table to reduce repetition. Table 5 presents the principal risk characteristics, recommended intervention package, and estimated cost.

Table 4. Integrated Priority-School Intervention Plan and Estimated Costs

Rank	School Zone	Road segment and key characteristics	Students (n)	Distance to high-risk area (km)	Proposed intervention package	Estimated cost (IDR)
1	SDN 1 Karangpanimbal	Jalan Siliwangi III; 2/2 undivided; located in a black area	127	0.0	Warning lights; overhead traffic signs; 75-cm traffic signs; thermoplastic and cold-applied pavement markings; installation and supporting safety facilities	161,710,436.21
2	Hegarsari Elementary Schools 7–9	Batulawang II Highway; 4/2 undivided; highest traffic volume and student population	287	1.4	Warning lights; overhead traffic signs; 75-cm traffic signs; thermoplastic and cold-applied pavement markings; installation and supporting safety facilities	146,342,461.46
3	SDN 1 Sukamukti	Jalan Raya Batulawang IV; 2/2 undivided; substantial student and traffic exposure	193	1.2	Warning lights; overhead traffic signs; 75-cm traffic signs; thermoplastic and cold-applied pavement markings; installation and supporting safety facilities	160,994,665.66

The estimated cost is highest for SDN 1 Karangpanimbal at IDR 161,710,436.21, followed by SDN 1 Sukamukti at IDR 160,994,665.66 and SDN 7–9 Hegarsari at IDR 146,342,461.46. The proposed packages share the same main facility types, while their estimated costs vary by location. These estimates can support preliminary budget allocation, subject to confirmation through detailed engineering design, quantity calculations, and applicable unit prices.

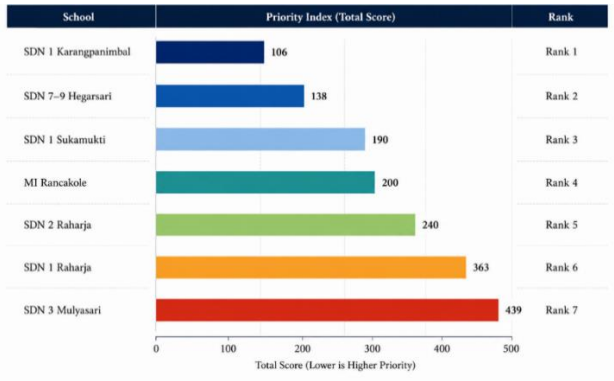


Figure 2. Priority Index of School Safety Zones

Site-Specific Design Drawings

The design drawings should be revised to clearly illustrate the proposed facilities and their spatial relationship to the school entrance and the surrounding road environment. Keep the three site-specific drawings, but ensure that each drawing includes the elements listed below.

SDN 1 Karangpanimbal — Priority 1

SDN 1 Karangpanimbal is located on Jalan Siliwangi III, a national road classified as a secondary arterial road with a 2/2 undivided cross-section. The school serves 127 students and is situated within an identified accident-prone area. Based on the WLC ranking results, these conditions establish SDN 1 Karangpanimbal as the highest-priority location for safety intervention. The proposed measures include conventional warning lights, overhead traffic signs, 75-cm

traffic signs, thermoplastic and cold-plastic pavement markings, as well as the installation of supporting safety facilities. According to the budget plan, the total estimated cost of the proposed interventions is IDR 161,710,436.21.

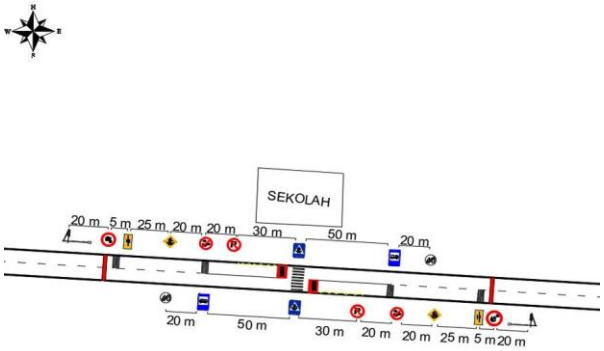


Figure 3. Proposed ZoSS Interventions at Priority School SDN 1 Karangpanimbal

SDN 7, SDN 8, and SDN 9 Hegarsari — Priority 2

The SDN 7, SDN 8, and SDN 9 Hegarsari school group is located on Jalan Raya Batulawang II, a national road classified as a secondary arterial road with a 4/2 undivided cross-section. The three schools collectively serve 287 students, representing the largest student population among the surveyed school locations. The school group is located approximately 1.4 km from an identified accident-prone area. The proposed interventions include conventional warning lights, overhead traffic signs, 75-cm traffic signs, thermoplastic and cold-plastic pavement markings, installation work, and supporting safety facilities. According to the budget plan presented in Chapter V, the total estimated cost of these interventions is IDR 146,342,461.46.

This location's second-place ranking underscores the importance of student exposure in determining priorities for school-zone safety interventions. Although the school group is not directly located within an identified accident-prone area unlike SDN 1 Karangpanimbal - its large student population along a single road corridor indicates the need for appropriate safety facilities. These facilities are intended to improve the visibility of school-zone warnings, increase driver awareness of the presence of schoolchildren, and support safer travel between the schools and their surrounding areas.

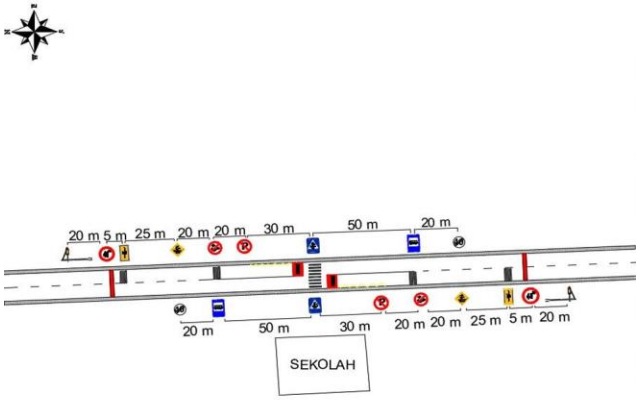


Figure 4. Proposed ZoSS Interventions at Priority School Locations: SDN 7, SDN 8, and SDN 9 Hegarsari

SDN 1 Sukamukti — Priority 3

SDN 1 Sukamukti is located on Jalan Raya Batulawang IV, a national road classified as a secondary arterial road with a 2/2 undivided cross-section. The school serves 193 students and is situated approximately 1.2 km from an identified accident-prone area. The proposed interventions include conventional warning lights, overhead traffic signs, 75-cm traffic signs, thermoplastic and cold-plastic pavement markings, installation work, and supporting safety facilities. The total estimated cost, as specified in the budget plan, is IDR 160,994,665.66.

SDN 1 Sukamukti ranks third in the intervention priority assessment, reflecting a combination of a relatively large student population and exposure to traffic along the Jalan Raya Batulawang IV corridor. The proposed interventions aim to improve the visibility of the school zone, provide clearer safety information to road users, and increase driver

awareness of the presence of schoolchildren. The selection and placement of the facilities should be guided by the site's existing conditions and the specific safety deficiencies identified during the assessment.

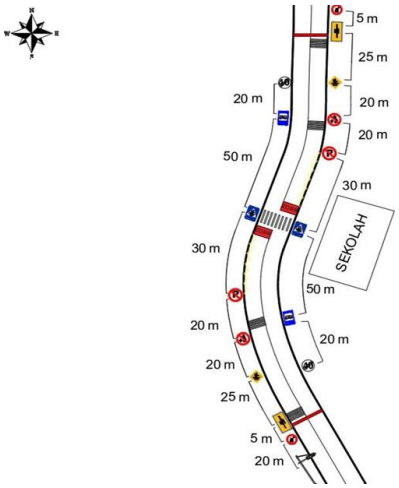


Figure 5. Proposed ZoSS Interventions at Priority School Locations: SDN 1 Sukamukti

Implementation and Evaluation Strategy

Implementation should follow a continuous cycle of risk identification, priority setting, construction or improvement of ZoSS facilities, and post-implementation evaluation. The initial evaluation is recommended three months after the facilities become operational, followed by evaluations every six months or sooner as needed.

The evaluation should examine the operational condition of the installed facilities, driver compliance with signs and markings, and students' ability to cross the road safely. If the expected safety conditions have not been achieved, corrective measures should be implemented and re-evaluated. Where performance is satisfactory, facilities should be maintained and monitored periodically. This cycle allows intervention decisions to be adjusted as traffic conditions, school activities, road conditions, and road-user behavior change.

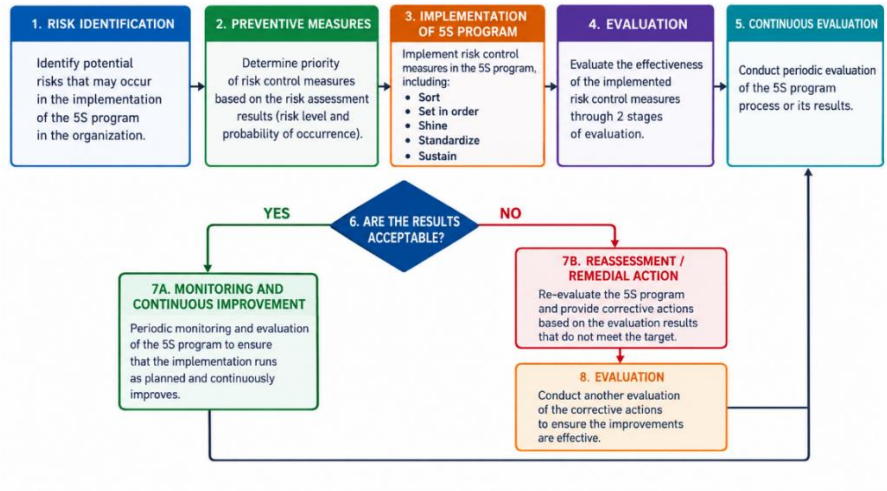


Figure 6. Proposed Implementation and Evaluation Cycle of ZoSS

The proposed implementation cycle emphasizes that the effectiveness of School Safety Zones (ZoSS) should be assessed not merely by the completion of physical facilities but also by their operational performance and measurable safety outcomes. If the evaluation indicates that the intended safety objectives have not been achieved, corrective measures should be implemented, followed by a subsequent evaluation to assess their effectiveness. Conversely, if the interventions produce satisfactory results, the facilities should be maintained and monitored periodically to ensure their continued functionality and effectiveness.

This framework supports an adaptive approach to road safety management, allowing intervention strategies to be reviewed and adjusted in response to post-implementation findings. Such an approach is particularly important because safety conditions in school zones may change over time due to variations in traffic characteristics, school

activities, road infrastructure, and road-user behavior. Accordingly, the priority assessment developed in this study should serve not only as a basis for determining initial interventions but also as a reference for ongoing monitoring, periodic evaluation, and continuous improvement of school-zone safety.

DISCUSSION

The research findings indicate that the need for improvements to School Safety Zones (ZoSS) in Banjar City varies by location. Based on the reported ranking results, SDN 1 Karangpanimbal ranks first with a score of 106, followed by SDN 7–9 Hegarsari with a score of 138, and SDN 1 Sukamukti with a score of 190. These three locations differ in terms of traffic conditions, student enrollment, and proximity to accident-prone areas. These findings highlight the importance of evaluating multiple factors collectively when identifying locations requiring safety interventions.

These findings align with those of [1], who demonstrated that children's safety in school zones is linked to traffic conditions, road user behavior, and the availability of infrastructure. [2] also found that high traffic volume and vehicle speed are critical factors in children's travel safety. In a study conducted in Banjar City, SDN 7–9 Hegarsari had the highest traffic volume at 502 vehicles per hour, a travel speed of 43 km/h, and a student population of 287. These conditions explain why Hegarsari requires special attention in safety facility planning. Nevertheless, the extent of each indicator's influence on the final score still needs to be demonstrated through WLC normalization and weighting results.

The prioritization results are also consistent with [5], who developed a data-driven approach to identify schools requiring safety improvements. Their study demonstrated that road characteristics and the school's surrounding environment can inform safety investment decisions. In this study, SDN 1 Karangpanimbal ranked as the top priority even though its traffic volume was lower than that of Hegarsari. Its location within an accident-prone area was a key consideration in the assessment. This finding suggests that the location with the highest traffic volume does not necessarily have to be the top priority, as there are other risk factors that must also be taken into account.

This study expands the discussion on school safety by linking risk rankings, facility conditions, and the costs required for remediation. [8] used interpretable machine learning to identify the relationship between road environmental conditions and pedestrian accidents in school zones. They demonstrated that the physical characteristics of the road environment are associated with the frequency of accidents resulting in serious injury or death. The study in Banjar City employed a simpler approach, namely combining six indicators using WLC. These differences indicate that school safety assessments can be conducted at various levels of complexity, depending on the analysis objectives and data availability.

Another perspective is presented by [10], who assessed potential traffic conflicts around schools based on spatial and temporal changes during the morning rush hour. That study showed that the potential for conflicts can vary across road segments and traffic periods. Meanwhile, the Banjar City study used traffic volume, degree of saturation, and travel speed as indicators of traffic conditions. Therefore, future research should consider specific measurements during students' arrival and dismissal times. Such measurements could help clarify whether average traffic conditions truly reflect the risks when large numbers of students are crossing the street.

Although this study recommends improvements to traffic signs, warning lights, road markings, and supporting infrastructure, several previous studies have shown that installing such infrastructure does not always result in significant safety improvements. [12] found that interventions involving signs, markings, and warning devices in school zones only resulted in a limited reduction in speed. That study emphasized the importance of physical road modifications and stricter speed enforcement. These findings present an important limitation for the Banjar City study, as the presence of facilities that meet the requirements does not automatically guarantee that vehicles will slow down.

References [15] also found that text-only warning signs did not result in a significant reduction in speed under their test conditions. Conversely, a combination of text and flashing lights resulted in a greater reduction in speed. These results indicate that the effectiveness of safety facilities is influenced by their design and the way they convey information to drivers. Therefore, recommendations for facilities in Banjar City need to consider not only the number of signs or markings but also their placement, visibility, and suitability for road characteristics.

Further evidence is provided by [13], who found that only 4.1% of drivers complied with the 30 km/h speed limit in the school zones studied in Ghana. These findings demonstrate that speed limits are not always followed by road users. This situation is relevant to the study in Banjar City, which recorded vehicle travel speeds between 37.5 and 43 km/h. However, without measurements of compliance with the applicable speed limits at each location, this study cannot yet

conclude the extent of driver violations. Observations of behavior and speed compliance are needed to complete the evaluation of traffic facilities.

Practical Implications

This study provides findings that the Banjar City Government can use to plan road safety improvements around schools. Of the seven school zones studied, three locations were identified as top priorities: SDN 1 Karangpanimbal, SDN 7–9 Hegarsari, and SDN 1 Sukamukti. These findings help the Department of Transportation determine which schools should receive improvements first. Consequently, the government does not have to allocate the budget equally among all schools but can prioritize locations with greater safety needs based on traffic conditions, student enrollment, facility availability, and proximity to accident-prone areas.

This study also produced safety facility improvement plans and cost estimates for these three locations. SDN 1 Karangpanimbal requires a budget of approximately Rp161.71 million, SDN 7–9 Hegarsari approximately Rp146.34 million, and SDN 1 Sukamukti approximately Rp160.99 million. The total estimated budget amounts to Rp469.05 million. The planned improvements include the installation of warning lights, traffic signs, road markings, and other safety support facilities. These three locations have a combined student population of 607. This means that if the improvements are implemented, 607 students stand to benefit from better safety facilities. The government can use these results as a basis for developing work programs, determining facility needs, and proposing construction budgets.

The benefits of the research can also be seen in how the government evaluates the results of the improvements after the facilities are installed. The Department of Transportation can measure vehicle speeds, driver compliance with traffic signs, and the safety of students while crossing the street. The first inspection can be conducted three months after the facilities are put into use, followed by subsequent inspections every six months. Schools can also use the research findings to identify locations requiring additional supervision when students arrive at and leave school. In this way, the success of the improvements is measured not only by the number of traffic signs or road markings installed but also by changes in road safety conditions. However, since facility improvements have not yet been implemented in this study, reductions in vehicle speed and the number of accidents cannot yet be cited as achieved outcomes.

CONCLUSION

This study shows that traffic conditions and safety facilities in seven school zones in the city of Banjar still vary. Traffic volume ranges from 177 to 502 vehicles per hour, with vehicle speeds between 37.5 and 43 km/h. An assessment of 18 types of safety facilities revealed that SDN 3 Mulyasari and MI Rancakole do not yet have facilities that meet the requirements, while SDN 1 Karangpanimbal and SDN 1 Sukamukti have a 83.3% deficiency in facilities. Based on the ranking results reported using the Weighted Linear Combination (WLC) method, the three top-priority locations are SDN 1 Karangpanimbal with a score of 106, SDN 7–9 Hegarsari with a score of 138, and SDN 1 Sukamukti with a score of 190. These three locations have different safety needs and therefore require improvements tailored to their respective conditions. This study also produced a renovation plan involving the installation of warning lights, traffic signs, road markings, and supporting safety facilities. The estimated total cost to renovate these three locations amounts to Rp469,047,563.33, with 607 students potentially benefiting from the improvements. The results of this study can help the government determine which schools need to be improved first, select the necessary facilities, and allocate the budget in a more targeted manner. However, the planned improvements have not yet been implemented, so their effectiveness in reducing accidents cannot yet be proven. Further research is needed to assess changes in vehicle speed, driver compliance, and student safety after the facilities are installed.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this research.

DATA AVAILABILITY STATEMENT

The data used in this study were obtained from field surveys and relevant institutions in Banjar City. Supporting data may be made available by the corresponding author upon reasonable request, subject to data-sharing permissions.

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DECLARATION OF AI TOOL USAGE

AI-assisted tools were used only to improve the language, grammar, sentence structure

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