

Improving Road Performance with the Target of Implementing a School Safety Zone

Manuscript received April 28, 2026; revised July 9, 2026

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Abstract—School drop-off and pick-up activities, where parents collect and drop off schoolchildren, cause traffic congestion, especially when the urban road lacks a school safety zone and pedestrian bridge. This also poses a risk to the safety of pedestrians and/or those crossing the road. This situation is evident in front of the school. Data collection over 6 days, consisting of traffic flow counts, vehicle speeds, and the number of side obstructions, was subsequently analysed using the Indonesian Road Capacity Manual, 2023, as a reference for road performance. The 2023 Sidewalk Planning Guidelines are used as a reference for planning sidewalk widths and types of pedestrian crossing facilities. Regulation of the Director General of Land Transportation 2018 is used as a reference for planning School Safe Zones. This study's results show the section's performance based on the degree of saturation: traffic flow is starting to become congested, and the pedestrian crossing facility that meets the needs in front of the school is a pedestrian bridge. The presence of a school safety zone and pedestrian bridge decreases the degree of saturation (44.85%) and increases light vehicle free flow speed (47%).

Keywords—capacity, degree of saturation, school safety zone, traffic accidents, transport system.

I. INTRODUCTION

The rate of accidents involving children on the roads continues to increase every year, particularly around school areas where students are walking and crossing the streets. Thousands of lives are lost every year due to traffic accidents worldwide, and youths are the most affected [1][2]. This issue is caused not only by the negligence of students while on the road but also by drivers operating vehicles at high speeds, the lack of road safety facilities, and inadequate road safety measures, especially around school zones [3]. First, they are the age group most affected by road trauma, with road traffic crashes being the leading cause of death among those aged 5-29 years. Second, they are the generations who will inherit the outcomes of decisions made today about the safety of the evolving transport system [4].

The area in front of the school is one of the traffic-prone spots because it is where various types of road users meet, such as students, teachers, parents, private vehicle drivers, and public transport users. For example, in front of PAI Elementary School (Perintis Kemerdekaan km.18 street, Makassar), there is heavy activity at drop-off and pick-up

times, increasing interactions between pedestrians and vehicles, which can potentially cause traffic conflicts. Traffic conflicts in front of schools usually arise due to several factors, including many school pick-up/drop-off vehicles stopping on the roadside or sidewalk, resulting in high vehicle volume during arrival and dismissal times; undisciplined driver behavior, such as sudden stopping, dropping off passengers in random places, or violating road markings; lack of crossing facilities, such as zebra crossings, speed bumps, or clear school zone warning signs; vehicle speeds that remain high despite being in a school area where maximum speed limits should be enforced; and a shortage of traffic controllers or supporting physical facilities, such as medians, guardrails, and sidewalks.

The school's access point is less than 2 meters from the roadway (Perintis Kemerdekaan km.18 street, Makassar). Perintis Kemerdekaan Road is an arterial road connecting the city center with Makassar's outskirts. The high volume of motorized vehicles, both private cars and public transport, has the potential to create traffic conflicts with pedestrians, especially in front of the school. The impact of these conflicts not only causes local congestion but also increases the risk of accidents involving students, who are the most vulnerable road users.

Based on initial field observations, the pedestrian facilities in front of PAI Elementary School still do not fully support the safety and comfort of users. Common problems encountered include limited sidewalks, a lack of safe crossing facilities, and pedestrians' disorderly behavior due to inadequate road conditions. Apart from causing unsafe conditions for school children walking/crossing the road, it also causes traffic jams. The research objectives of this study are to determine the performance of road sections (light vehicle free flow speed and degree of saturation) without school safety zones, the types of pedestrian crossings that suit the needs at the location, and the influence of the presence of school safety zones and pedestrian crossing facilities on the performance of the section.

The research gap in the study are the observation time for 6 days a week, the performance of the section, namely the degree of saturation referring to the 2023 Indonesian Highway Capacity Manual (IHCM), a 10-minute survey time interval, recording of side friction events based on their type, namely parked vehicles, vehicles entering and exiting plot access,

slow-moving vehicles/non-motorized vehicles, and pedestrians.

Previous research related to school safety zones has discussed traffic safety, but no articles have yet discussed the effect of implementing school safety zones and pedestrian crossings on traffic performance (degree of saturation and average free-flow speed of light vehicles). Fig. 1 shows the location of the study.



Fig. 1. Location of study

Some previous studies related to traffic in front of schools show that traffic in front of the school experiences conflict, especially during activities of dropping off and picking up school children, as well as crossing the road[18]. The provision of school safety zones is expected to improve the performance of road sections [19]. With the presence of signs prohibiting parking near school areas, reducing speed, being careful in school areas, and crossing roads, drivers are more careful. Additionally, reducing peak-time on-street parking near schools significantly improves pedestrian safety [20]-[22]. Implementation of school safety zones on road sections in school areas that have high levels of pedestrian traffic and are prone to traffic accidents[23] [24].

That children have difficulty understanding and predicting the behavior of other road users and adapting their own behavior accordingly. This is due to their still limited cognitive capacities and skills, as well as perceptual and motor abilities[5]. The high vulnerability of pedestrians in road traffic crashes highlights the need to implement effective interventions to protect pedestrians. The identification of effective interventions related to pedestrians strengthened the system to achieve pedestrian safety goals [6][7].

Traffic accidents that occur in school children can be caused by schools that are close to the highway and a lack of knowledge of traffic safety regarding the movement of school students to and from school[8]. Risk-taking behaviours increase with age and peer interaction, especially during the afternoon hours. The role of crossing guards shows mixed effectiveness due to variations in implementation and local context. By operationalizing the Safe System approach through synergistic infrastructure, enforcement, and education strategies, the project achieved statistically significant reductions in vehicle speeds and crash incidence, while elevating school zone safety ratings to international standards [9]. Traffic safety education in schools significantly increases students' understanding and awareness of traffic safety [10].

that visual nudges can be useful in reducing risky dismounting behavior at zebra crossings in elementary school zones.

However, only short-term behavioral changes immediately following the implementation of the nudge were assessed[11][12]. The socioeconomic status of the school's neighborhood was found to induce mixed effects on the injury severity risk [13]. Factors such as plant density, turning angle, road scale, road slope, recognizable signs, internal corner space, animal danger, enclosure type, electronic tools, monitoring facilities, strangers, and social concerns were found to be significantly related to road safety perceptions of left-behind children traveling independently [14][15]. The traffic safety interventions will be more effective in improving traffic literacy among children with lower levels of baseline traffic safety literacy, given they started with inferior levels of knowledge, attitudes, behaviors, and self-efficacy [16][17].

II. METHODOLOGY

Primary data collection was conducted through field surveys on weekdays, with observation times ranging from 6 AM to 5 PM, to represent traffic conditions during the morning, afternoon, and evening peak hours. The traffic volume survey was conducted using a direct enumeration method of the number of passing vehicles by vehicle type: motorcycles, passenger cars, and medium-sized vehicles. This data was used to determine traffic flow in passenger car units (PCU/hour) in accordance with the 2023 Indonesian Highway Capacity Manual (IHCM)[25]. The 2023 IHCM (Indonesian Highway Capacity Manual) is used as a reference in this research on the basis that motorcycles are the largest proportion of all vehicle types on Indonesian roads. In addition to the composition and number of vehicles by type, the IHCM takes into account adjustment factors that affect road performance, namely adjustments for effective lane width, city size, directional split, and the type and number of side friction. Fig. 2 shows the research framework.

The 2023 Sidewalk Planning Guidelines are used as a reference for planning sidewalk widths and types of pedestrian crossing facilities[26]. Determination of the type of pedestrian crossing facility based on the number of conflicts between pedestrians and motorized vehicles (PV^2). Determination of the minimum sidewalk width based on the highest number of pedestrians per meter per minute and environmental condition factors; if in front of a school, the factor value is 1.5. Regulation of the Director General of Land Transportation No. SK.3582/AJ.403/DRJD/2018 (revised SK.1304/2014) is used as a reference for planning School Safe Zones[27].

Side friction data obtained from the survey results were calculated based on the frequency of side friction occurrences per hour. This data was then used to determine the class of side friction that will affect the capacity and speed of free flow in accordance with the 2023 Indonesian Highway Capacity Manual. Vehicle travel time data was used to calculate average vehicle speed by comparing distance traveled and travel time. This speed was used to determine the actual vehicle speed conditions on the study road section.

III. RESULT AND DISCUSSION

A. Traffic Volume

Traffic volume was collected based on traffic direction, namely to Maros (South to North) and to Makassar (North to South). The highest volume/peak hour was obtained in each direction and observation day, namely on Monday morning, when many motorized vehicles moved towards Maros, namely 4201 vehicles/hour, while on Monday afternoon in the opposite direction, as many as 4,298 vehicles/hour. On

Tuesday morning, the highest volume of 4,151 vehicles/hour of vehicle movement was towards Makassar, while in the afternoon, 4255 vehicles/hour moved towards Maros. On Wednesday, peak hours occurred in the afternoon with vehicle

movement towards Makassar, and in the afternoon towards Maros.

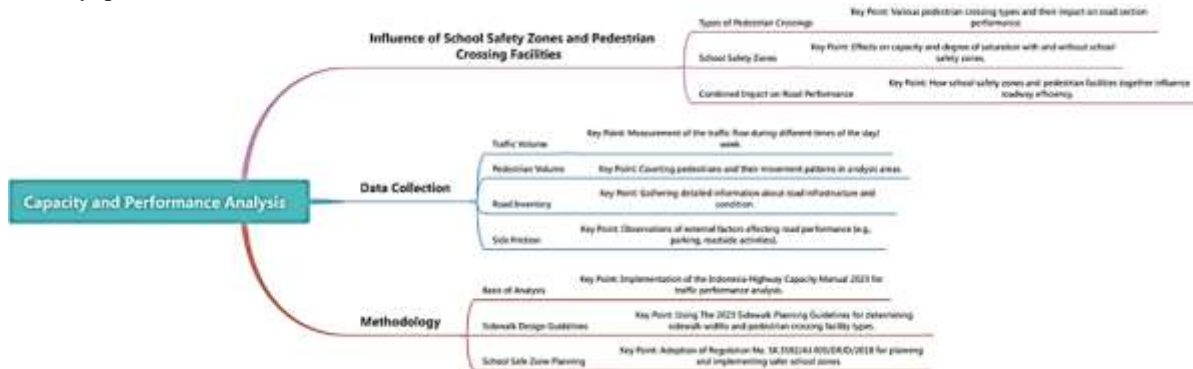


Fig. 2. Research framework

The movement of motorized vehicles towards Makassar on Thursday morning was 4,155 vehicles/hour, while in the afternoon towards Maros, 4,233 vehicles/hour. On Friday morning, peak traffic to Makassar occurs at 4,271 vehicles per hour, while in the afternoon, traffic to Maros is at 4,220 vehicles per hour. Saturday is a day with peak traffic to Maros occurring in the morning, while in the afternoon, traffic to Makassar is at its peak. Monday, which has the densest volume, is then used as a reference for the analysis of the performance of pedestrian sections and facilities/school safety zones (ZoSS). The number of vehicles during peak hours by traffic direction is presented in Table I.

TABLE I. NUMBER OF VEHICLES DURING PEAK HOUR BY TRAFFIC DIRECTION (VEHICLES/HOUR/DIRECTION)

Day	South – North (Vehicle/hour)	North – South (vehicle/hour)	Time
Monday	3638	4298	2.40-3.40 PM
	4201	2470	10.30 – 11.30 AM
Tuesday	4255	3244	3.30 – 4.30 PM
	2607	4151	10.30 – 11.30 AM
Wednesday	4161	3290	3.40 – 4.40 PM
	2950	4222	1 – 2 PM
Thursday	4233	2846	12 – 1 PM
	2393	4155	9 – 10 AM
Friday	4220	2820	1.30 – 2.30 PM
	2811	4271	9.30 – 10.30 AM
Saturday	3079	4058	4 – 5 PM
	3877	2866	8.30 – 9.30 AM

Based on the results of the addition of vehicles per hour, which is more than 1,050 vehicles/hour during peak hours, the type of 4/2D passenger car equivalent (PCE) that will be used is 1.2 medium vehicles and 0.25 motorcycles. The peak flow from daily observation data is used to represent the weekly traffic flow, namely the peak traffic flow. After converting from vehicle units per hour to passenger car units/hour, the traffic volume based on direction is obtained, namely Monday towards Makassar 2,473.75 pcu/hour, Tuesday towards Makassar, 2,450.5 pcu/hour, Wednesday towards Maros, 2,408.5 pcu/hour, Thursday towards Maros, 2,493 pcu/hour, Friday towards Maros, 2,526 pcu/hour, and Saturday towards Maros, 2,329.45 pcu/hour. The number of passenger car units during peak hours based on traffic direction is presented in Table II.

B. Side Friction

The side friction analysis on Perintis Kemerdekaan km. 18 street was carried out along 200 m. Side friction includes the number of pedestrians, parked vehicles, slow-moving vehicles, and vehicles entering and exiting the plot access.

TABLE II. NUMBER OF PASSENGER CAR UNITS DURING PEAK HOUR BY TRAFFIC DIRECTION (PASSENGER CAR UNIT/HOUR/DIRECTION)

Day	South-North Passenger car unit/hour	North – South Passenger car unit/hour
monday	2,489.05	2,473.75
tuesday	2,383.3	2,450.5
wednesday	2,408.5	2,403.75
thursday	2,493	2,394.35
friday	2,526	2,429.75
saturday	2,329.45	2,259.2

The weight for each type of side friction is 0.5 for pedestrians, 1.0 for parked vehicles, 0.4 for slow-moving vehicles, and 0.7 for vehicles entering and exiting the plot access. Based on peak hours, the number of side friction is the direction to Makassar on Monday, 733.4 events, on Tuesday, the direction to Makassar 779.7 events, on Wednesday the direction to Makassar, 777.2 events; on Thursday, the direction to Makassar, 837.4 events, on Friday the direction to Maros, 759.5 events, and on Saturday the direction to Maros, 805 events. The total number of side friction based on the observation day is presented in Table III.

TABLE III. NUMBER OF SIDE FRICTION DURING PEAK HOUR BY TRAFFIC DIRECTION (EVENT/HOUR/DIRECTION)

Day	Side Friction	
	North-South	South-North
Monday	725	733.4
Tuesday	745.5	779.7
Wednesday	762.7	777.2
Thursday	770.9	837.4
Friday	759.5	755.5
Saturday	805	745.1

C. Degree of Saturation

The degree of saturation is the level of road utilization, the ratio of capacity to volume. A degree of saturation (Dj) value approaching 1 indicates traffic congestion.

The highest volume in each direction of traffic, including the weight of side friction events, namely on Monday, is used to calculate the degree of saturation and free flow speed

values. Capacity is calculated with correction factors applied to the capacity (formula (1)):

$$C = C0 \times FCLJ \times FCPA \times FCHS \times FCUK \quad (1)$$

Where

$C0 = 2 \times 1700 = 3,400$ passenger car unit/hour
 adjustment factor due to lane width, $FCLJ = 0.92$
 adjustment factor due to direction separation, $FCPA = 1.00$
 adjustment factor due to side friction, $FCHS = 0.88$
 adjustment factors due to city size, $FCUK = 1.00$

$$C = 3,400 \times 0.92 \times 1.00 \times 0.88 \times 1.00 = 2,752 \text{ passenger car } \frac{\text{unit}}{\text{hour}}$$

The degree of saturation is calculated using formula number 2, namely:

North – South:

$$\text{Degree of saturation, } Dj = \frac{q}{c} \quad (2)$$

Where

q = volume (passenger car unit/hour)

C = capacity (passenger car unit/hour)

$$Dj = \frac{2,459.97}{2,752} = 0.89 > 0.85$$

South – North

$$Dj = \frac{2,430.42}{2,752} = 0.88 > 0.85$$

According to the 2023 IHCM, a saturation level of an urban section exceeding 0.85 indicates unstable traffic flow and traffic congestion.

D. Free Flow Speed

In calculating the free flow speed, IHCM, 2023 sets passenger cars as the reference vehicle. Based on the 4/2D road type, the free flow speed (VBD) is 57 km/hour. The determination of the lane width adjustment factor (VBL) is determined based on the effective lane width by looking at the width per lane. Based on the VBL value, the lane width is 2.95 m using data extrapolation. The result of the 2.95 m lane width data extrapolation is -4. Side Friction Adjustment Factor on Shouldered Roads (FVBHS). Based on the calculation and reading results from Table III, Perintis Kemerdekaan km 18 street, the side friction class is high. For the 4/2D road type with an effective shoulder width of less than or equal to 0.5 m, the FVBHS value is 0.89. City Size Adjustment Factor (FVBUK): Based on the population of Makassar City, which is 1,770,180 people, the city size adjustment factor (FVBUK) is 1.00.

Free flow speed is calculated using formula (3).

$$VBD = 57 \text{ kilometer/hour), } VBL = -4 \text{ kilometer/hour}$$

$$FVBHS = 0.89$$

$$FVBUK = 1.00$$

$$VB = (VBD + VBL) \times FVBHS \times FVBUK \quad (3)$$

$$VB = (57 + (-4)) \times 0.89 \times 1.00 = 47 \text{ kilometer/hour}$$

The relationship between the degree of saturation and the average speed of light vehicles per direction, for the directions north to south and south to north, from Figs.s 3 and 4, the average free flow speed of light vehicles is 35 kilometers/hour (north-south) and 37 kilometers/hour (south-north).

The average actual speed is obtained as the travel speed of the surveyed vehicles during peak traffic conditions. The average speed of light vehicles in actual conditions for Monday in the direction of Maros, namely 18.72 kilometers/hour, means the speed of vehicles in heavy traffic conditions.

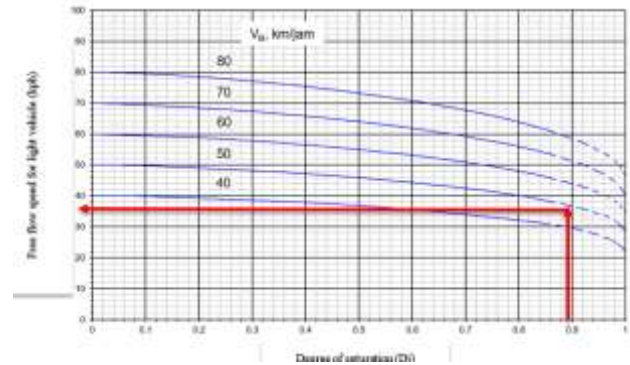


Fig. 3. Free flow speed of light vehicle (north-south)

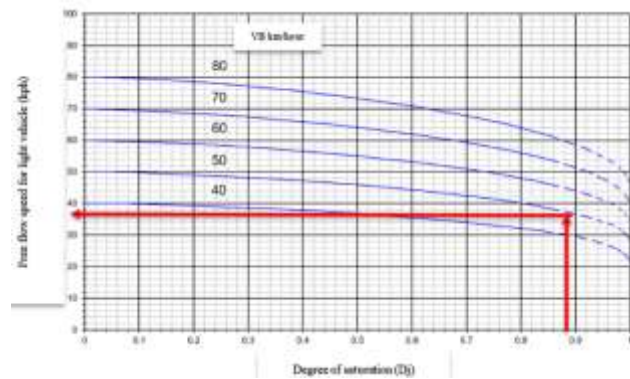


Fig. 4. Free flow speed of light vehicle (south-north)

The actual vehicle speed can be calculated using formula (4) as follows:

$$\bar{V}_s = \frac{n \cdot L}{\sum_{i=1}^n t_i} \quad (4)$$

Where

$\bar{V}_s$ = space mean speed (kilometer/hour)

n = number of samples

L = length of segment (meter)

t_i = time (hour)

$$\bar{V}_s = \frac{15 \times 100}{288.45} = 5.20 \text{ meter/second} = 18.72 \text{ kilometer/hour}$$

TABLE IV. ACTUAL SPEED OF LIGHT VEHICLE (KILOMETER/HOUR/DIRECTION)

Day	Actual speed of light vehicle (km/hour)	
	North-South	South-North
Monday	18.72	16.42
Tuesday	15.13	16.54
Wednesday	17.56	18.82
Thursday	17.33	17.94
Friday	16.85	18.05
Saturday	18.65	18.43

The actual average speed of vehicles in front of schools is 15.13 kilometer/hour to 18.82 kilometer/hour. This is supported by previous research, which found that vehicle speeds in front of schools range from 12 to 21 km/hour [28]. When vehicles pick up and drop off school children, the speed

of vehicles on the road will decrease compared to the speed of vehicles during non-routine school hours. The resulting congestion and delays stem from non-routine movements [29].

E. Pedestrian

The highest number of pedestrians crossing the road was on Monday afternoon, namely 27 pedestrians. Based on the total number of pedestrians crossing the road during the observation period, on Monday there were 58 pedestrians, on Tuesday 55 pedestrians, on Wednesday 57 pedestrians, on Thursday, Friday, and Saturday, respectively 45 pedestrians, 49 pedestrians, and 27 pedestrians. In the morning and afternoon, there were more pedestrians crossing the road than in the afternoon, because most of the pedestrians were parents and school children who were being picked up or dropped off at school. Saturday had the fewest pedestrians, because there were no activities at school on this day. The number of pedestrians crossing the road during peak hours based on the observation day is presented in Table V.

After obtaining the total value of the maximum pedestrian volume of 27 pedestrians/hour (on Monday) and the maximum traffic volume of 7,337 vehicles/hour (on Monday).

TABLE V. NUMBER OF PEDESTRIAN CROSSINGS

Day	Morning	Noon	Afternoon
Monday	25	27	6
Tuesday	22	25	8
Wednesday	25	26	6
Thursday	27	16	2
Friday	23	17	9
Saturday	10	6	11

By using formula (5), the PV^2 value is obtained as:

$$PV^2 = 27 \times 7,337^2 = 145.345 \times 10^8 \quad (5)$$

Where

P = number of pedestrian

V = traffic volume

The vehicle volume value is quite high; thus, it is recommended to use a type of pedestrian crossing facility, namely a pedestrian bridge.

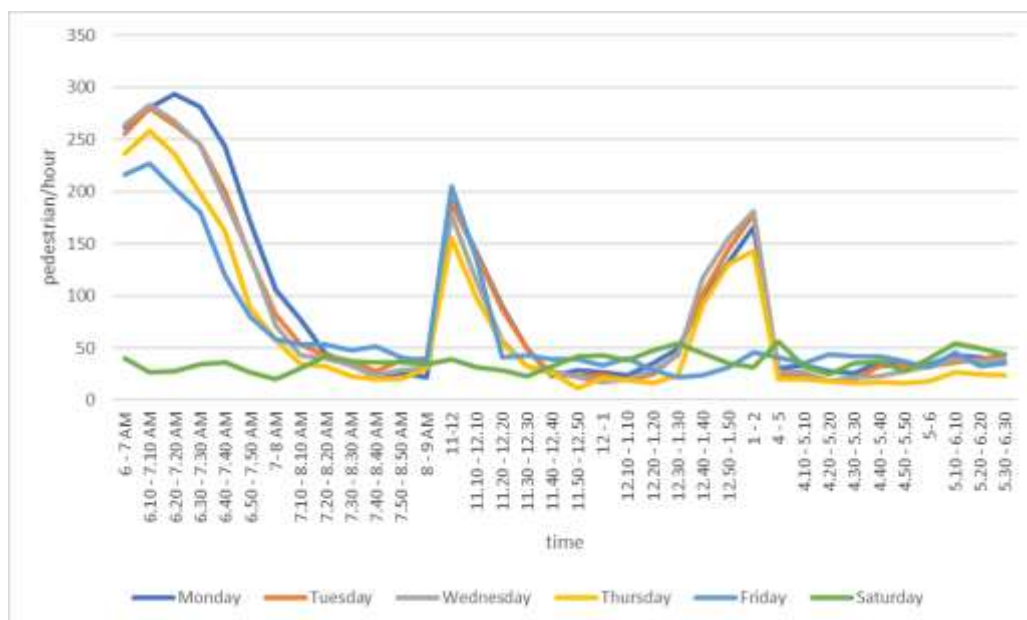


Fig. 5. Fluctuation of pedestrian

Fig. 5 shows the hourly fluctuations in pedestrian traffic per day of observation. Morning and afternoon are the peak periods for pedestrian traffic. Monday mornings are particularly high for pedestrian numbers. The Perintis Kemerdekaan Road section at KM.18 has been equipped with adequate crossing facilities, such as zebra crossings, but has not been equipped with pedestrian bridges, even though the road is quite long and busy with pedestrians. According to pedestrian facility planning standards, crossing facilities should be available every 100-200 meters to ensure optimal accessibility. Therefore, it is necessary to repaint road markings and add signs such as pedestrian signs, school warning signs, crossing signs, and speed limit signs to improve the safety and comfort of pedestrians.

In the morning, the number of pedestrians per meter per minute is at its highest, reaching 5 pedestrians/meter/minute. The majority of pedestrians in the morning are parents accompanying their children to school. Fig. 6 shows the

fluctuation of pedestrians per meter per minute in front of the school.

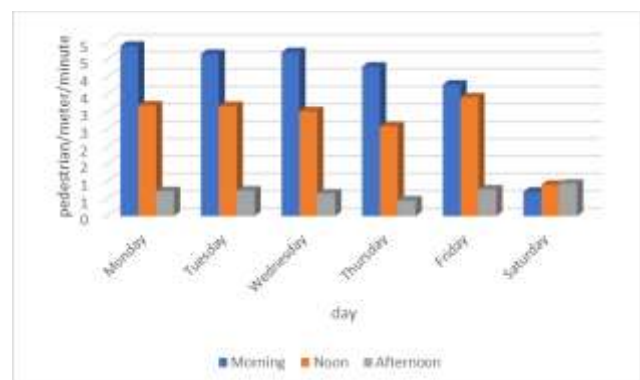


Fig. 6. Fluctuation of pedestrians at peak hour (pedestrian/meter/minute)

Calculation of sidewalk requirements using formula (6) as follows:

$$W = \frac{V}{35+N} \quad (6)$$

$$= \frac{5}{35 + 1.5}$$

With the planned pedestrian volume/2 directions (people/metre/minute), 5 were taken from the maximum number of pedestrians during observations, and the value of $N = 1.5$ (road sections where there are schools). The calculation results for the minimum width of the sidewalk are 2.274 meters, so this is in accordance with the regulations for Sidewalk Planning Guidelines for land around schools, which is 2 meters.

Stopping sight distance, Jh , is necessary to determine the minimum distance for placing warning signs to alert drivers to the presence of pedestrians and pedestrian crossings. This allows motorists to reduce their speed. Stopping sight distance calculation using formula (7).

$$Jh = 0.278 V t + 0.039 \frac{V^2}{254 f} \quad (7)$$

$$= 0.278 \times 68.944 \times 2,5 + 0.039 \frac{68.944^2}{254 \times \frac{3.4}{9.81}}$$

$$= 50.022 \text{ meters}$$

The minimum stopping sight distance and distance for placing warning signs for pedestrians and pedestrians is 50.022 meters from PAI Elementary School.

When improvements are made to road sections with school safety zones and pedestrian bridges, the correction factor value due to side friction is 1.01, and the lane width correction factor is 1.00. Using equations (1) and (2), the road capacity obtained is 3,434 PCU/hour, and the degree of saturation is 0.718 (north to south) and 0.707 (south to north). The free flow speed for the northbound and southbound directions becomes 40 kilometer/hour and 41 kilometers/hour, respectively. The performance of the road section increased by 44.58% (degree of saturation) and 47% (light vehicle free flow speed). Fig. 7 shows the north-to-south free-flow speed, and Fig. 8 shows the south-to-north free-flow speed. Table VI shows a comparison of road performance with and without school safety zones and pedestrian bridges. Fig. 9 shows a comparison of degree of saturation without and with school safety zones and pedestrian bridges. Fig. 10 shows a comparison of free flow speed without and with a school safety zone and pedestrian bridge

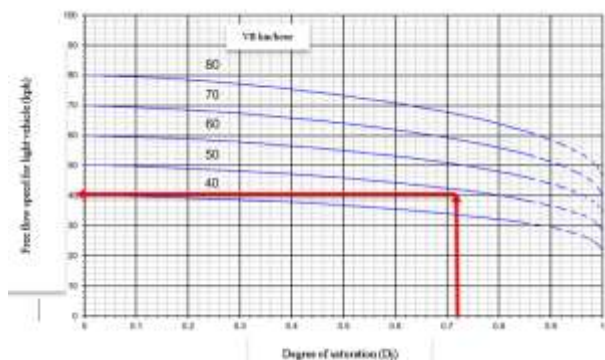


Fig. 7. Free flow speed of light vehicle (north-south)

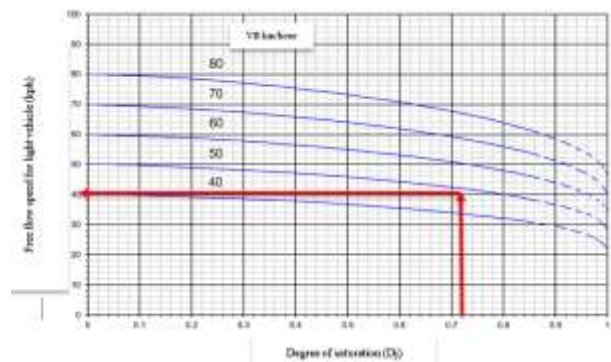


Fig. 8. Free flow speed of light vehicle (north-south)

TABLE VI. COMPARISON OF ROAD PERFORMANCE WITH AND WITHOUT SCHOOL SAFETY ZONES AND PEDESTRIAN BRIDGES.

Condition	Degree of saturation			Free flow speed of light vehicle (kilometer/hour)		
	North-south	South-north	Average	North-south	South-north	Average
Without School safety zone and pedestrian bridge	0.89	0.88	0.885	35	37	36
With School safety zone and pedestrian bridge	0.718	0.707	0.712	40	41	40.5

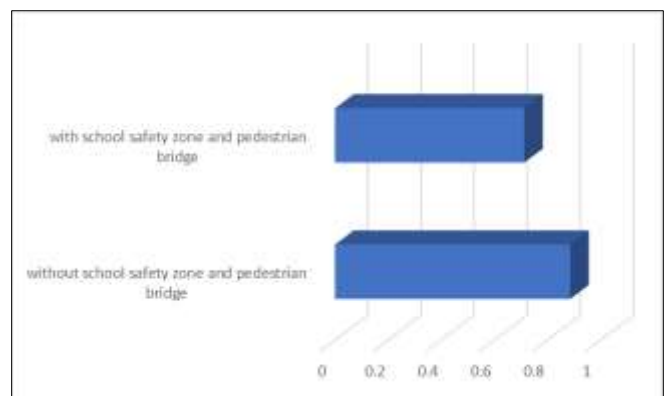


Fig. 9. Comparison of degree of saturation without and with school safety zone and pedestrian bridge

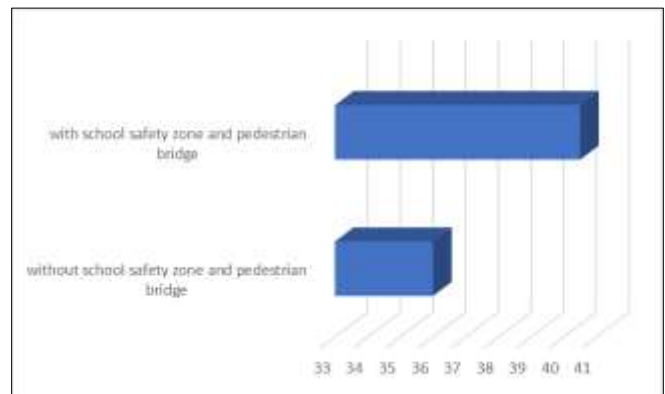


Fig. 10. Comparison of free flow speed without and with school safety zone and pedestrian bridge

F. Discussion

Based on observations at the research site, students cross the road directly to and from the school area without any crossing facilities to guide their movement. Crossings are made by exploiting available gaps between vehicles during traffic flow. This situation results in irregular pedestrian movement patterns that are difficult for drivers to predict. The dominant conflict points are in front of the school entrance and where vehicles stop to pick up and drop off passengers. At the same time, other vehicles continue to move at a high volume, increasing the potential for dangerous interactions between vehicles and students. The highest crossing activity occurs during school hours. During these periods, vehicle volumes increase, while the need for students to cross is also high, making the risk of conflict unavoidable.

The analysis shows that the degree of saturation in both directions remains below the critical limit, but is approaching a congested condition. With high volumes and a high level of side resistance, vehicle movement is dynamic. Although the actual measured speed is lower than the free-flow speed, vehicles continue to move in large numbers, thus maintaining a high risk to students crossing the road.

Given the combination of traffic volume, saturation level, and high student activity, this location is suitable for implementing a School Safety Zone (ZoSS). ZoSS is necessary to increase driver attention while providing additional protection for pedestrians.

School zone markings are necessary to provide early warning to drivers that they are entering an area with high student activity. Speed limits are needed so that drivers adjust their vehicle speed to the conditions of the school

environment. Adequate sidewalks will help separate pedestrian movement from vehicles and increase students' sense of safety. Devices such as speed tables or rumble strips can enhance efforts to reduce vehicle speed before reaching the crossing point. The presence of school safety zones and pedestrian bridges in front of schools improves traffic performance. This finding is also reinforced by previous research indicating that the presence of traffic calming measures in front of schools reduces the risk of accidents involving schoolchildren.[30]. That Attitude (ATT), Subjective Norms (SN), Perceived Behavioral Control (PBC), and Mindfulness (MF) reduce speed [31]. Collaboration on traffic calming measures is more effective in reducing vehicle speeds and the risk of accidents in front of schools [32][33]. Traffic calming measures that can be implemented in school areas, such as adequate signage, pavement markings, and pedestrian footbridges [34].

The School Safety Zone (ZoSS) design is planned with the addition of facilities in the form of red ZoSS markings, zig-zag markings, school warning signs, and speed limit signs in accordance with the ZoSS Technical Guidelines. The implementation of these facilities aims to reduce vehicle speeds and increase driver awareness in school areas. This is in line with the concept of road section performance according to IHCM 2023, where speed control is one of the efforts to improve the level of road service and traffic safety. With the implementation of a school safety zone (ZoSS), it is expected that vehicle speeds can be controlled, the degree of saturation remains stable, and it can improve safety for pedestrians, especially school students. The school safety zone plan can be seen in Fig. 10.

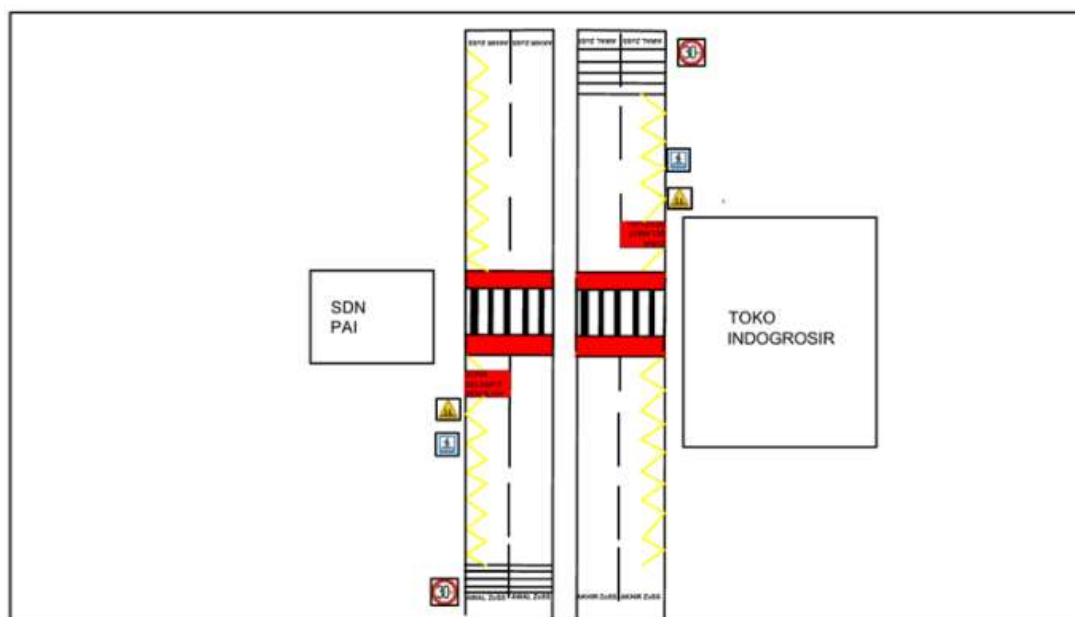


Fig. 11. The school safety zone plan

The degree of saturation, D_j , value increases due to high vehicle volume, especially during school entry and exit hours. The decline in road performance is due to pick-up drivers parking their vehicles on the side of the road, and during the waiting time, traffic flow becomes unstable due to reduced road capacity. This statement is reinforced with the results of previous research, namely that during the waiting time for pick-up drivers (an average of 8.48 minutes), they engage in numerous illegal parking actions on the road, which causes many "cognitive" errors and "crash" points around the front of

the elementary school entrance gate. [35]. Additionally, other research suggests that the absence of on-street parking is associated with slightly worse congestion levels, as managed on-street parking or lay-bys help absorb pick-up and drop-off activities more efficiently [36].

The analysis of the actual average speed of the space was conducted to obtain a more representative picture of the overall traffic flow conditions. The obtained value of the space mean speed shows the actual movement conditions of vehicles in the field. When compared to the area's function as a school

environment, the speed value indicates the need for more traffic control to support student safety. In addition, the presence of side friction (parking and pedestrian) also reduces the actual average speed of the space. This statement is supported by previous studies of previous research, namely that the type of street and the level of roadside activity were negatively correlated with vehicle speeds [37].

Based on the relationship between Dj values, average speed, and average actual speed of space, it can be concluded that traffic conditions around schools have potential risks to student safety. Direct interaction between motorized vehicles and students crossing without adequate safety facilities strengthens the urgency of handling. Therefore, it is necessary to identify and plan the design of School Safety Zones (ZoSS), which includes the provision of special ZoSS markings, school area speed limit signs, clear and safe crossing facilities, sidewalk improvements, and the implementation of vehicle speed controls. This discussion answers the fourth problem formulation and fulfills the fourth research objective in identifying the need for ZoSS design that is appropriate to traffic conditions and the needs of students around the school location.

IV. CONCLUSION

Based on the results of traffic volume analysis, degree of saturation, average vehicle speed, and average actual speed of vehicle space, the condition of Jalan Perintis Kemerdekaan km 18 in front of PAI Elementary School shows a high level of safety risk for students. The degree of saturation without and with a school safety zone is 0.885 and 0.712, respectively. The free-flow speed for light vehicles without and with a school safety zone is 36 kilometers/hour and 40.5 kilometers/hour, respectively. Therefore, it is necessary to implement and design a School Safety Zone (ZoSS) including the installation of school area markings, speed limit signs, zig-zag markings, and standardized crossing facilities to improve the safety of students and road users. In future research, it is hoped that there will be a comparison of student safety levels in locations that have school safety zones and those that do not have school safety zones.

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