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Pedestrian Crossing Safety Model for Unsignalized Three-Leg Intersection Based on User Perception Data

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ABSTRACT Recent statistics show an upward trend in road crashes in Indonesia, with pedestrians identified as the most vulnerable group of road users, thus addressing this issue requires evidence-based tools to support decision-making for pedestrian safety improvement. This study develops a perception-based Pedestrian Intersection Safety Index (PedISI) model using multiple linear regression to estimate safety levels at three-leg unsignalized intersections based on traffic and geometric characteristics. Unlike previous studies that rely on crash or behavioral data, this research employs user perception data, offering a lower-risk and more flexible means of capturing pedestrians' subjective evaluations of safety. The study was conducted at 15 unsignalized three-legged intersections comprising 42 observation points in Cimahi City, West Java, Indonesia. Data were collected on traffic volume, 85th percentile vehicle speed, lane width, and median width, alongside respondents' safety ratings derived from on-site video-based surveys. The results indicate that traffic volume, 85th percentile speed, lane width, and median width significantly influence pedestrian perceptions of crossing safety. Application of the developed regression model shows that the average perception-based pedestrian safety index at these intersections is 2.96. Sensitivity analysis further reveals that reductions in vehicle speed yield the greatest improvements in perceived safety, suggesting that speed management should be prioritized in pedestrian safety interventions. While geometric factors such as lane and median width also play a role, these must be optimized within design standards to balance safety and traffic performance. The study highlights the potential of perception-based modeling as a complementary approach for pedestrian safety assessment in data-limited urban environments and provides a framework for future applications incorporating diverse environmental and behavioral contexts.

KEYWORDS Pedestrian Safety; Perception-based Model; Unsignalized Intersection; PedISI Model; Multiple Linear Regression.

1 INTRODUCTION

Indonesia has experienced a dramatic increase in the number of motor vehicles, reaching approximately 153 million units in 2023 (Gaikindo, 2023). This rapid growth has had a considerable impact on road safety, as reflected in the rising number of traffic crashes nationwide. Traffic crashes not only pose significant public health risks but also result in major economic losses for both the government and the broader community. In light of these concerns, there is a compelling need to conduct research focused on pedestrian crossing safety as a foundation for implementing more effective safety measures.

Among the least-studied facilities for pedestrian safety are unsignalized three-leg intersections. Previous studies on pedestrian safety have concentrated more on four-leg intersections (Hashemi et al., 2022) , mid-block / median crossings (Avinash et al., 2019; Fitzpatrick et al., 2024; Zhang et al., 2019), and roundabouts (Xu et al., 2018). Yet, three-leg intersections have several characteristics that may impose greater risks to pedestrians when crossing, such as higher turning movement, visibility and gap acceptance, and priority ambiguity (da Costa et al., 2016). This paper addresses this issue by developing a pedestrian crossing safety model specifically for unsignalized three-leg intersections and explicitly considering their characteristics, such as approaching traffic speed.

This paper aims to develop a pedestrian crossing safety model for unsignalized three-leg intersections using a multiple linear regression model that refers to the PedISI (Pedestrian Intersection Safety Index) framework developed by Center (2007) and then later adopted by the Federal Highway Administration (FHWA). The primary outcome of this research is a safety index that can be used to prioritize interventions at intersections and guide the development of effective strategies for enhancing pedestrian safety in urban environments. The dependent variable in the model is the average safety rating provided by survey respondents, while the independent variables include the physical and traffic characteristics of the intersections.

One primary data requirement for the PedISI model is behavioral data, such as near-miss incident or crash incident recorded at the study location (Avinash et al., 2019; Fitzpatrick et al., 2024). However, this study specifically utilizes user perception data due to the lack of recorded data and the risk associated with collecting behavioral data, such as near-miss incident in the study location (Ogwude et al., 2025). On the other hand, the usefulness of using user-perception data is known form literature. Among its advantages are the low-risk data collection process, the ability to identify hidden safety issues and addressing the problem of the lack of recorded behavioral data (Ihssian and Ismail, 2023; Kwon et al., 2022). Nevertheless, user perception data have their own issues, such as subjectivity bias, limited predictive power, and difficulty in making comparison across sites, particularly if the study is conducted a specific location (Zhu et al., 2025).

This study uses the Cimahi City and its pedestrians as a case study, which raises questions about the generalizability and transferability of the resulting model to other urban contexts. The paper addresses these limitations by discussing how case-specific factors may influence the model's applicability elsewhere and proposes strategies to enhance generalizability, such as systematic data collection, validation through cross-validation techniques, and the use of objective, widely observable road and traffic variables.

2 LITERATURE REVIEW

Research on pedestrian safety at intersections has been conducted extensively over the years to identify influencing factors and develop effective evaluation models based on regression models. Early approaches to pedestrian safety primarily focused on analyzing crash trends through police reports and applying statistical measures to improve safety outcomes. For example, Jaskiewicz (2000) introduced a nine-metric evaluation system encompassing aesthetics, safety, and mobility to assess pedestrian environments in Winter Park, Florida. Using a five-point Likert scale, the study derived overall levels of service (LOS) scores to identify pedestrian deficiencies and suggest physical and policy-based improvements.

A significant contribution in measuring pedestrian safety using a regression model approach was the development of the Pedestrian Intersection Safety Index (PedISI). This model is an advancement of a macro-level pedestrian safety index developed by Center (2007). This model was formulated by the Federal Highway Administration (FHWA) with the aim of facilitating transportation engineers, urban planners, and other practitioners in proactively prioritizing pedestrian safety at crosswalks and intersection approaches based on intersection characteristics. By utilizing variables that indicate an elevated risk to pedestrians, the PedISI model enables the identification of crosswalks and intersection approaches that warrant the highest priority for pedestrian safety improvements within a specific study area. Once high-priority locations are identified, the local authority can conduct more detailed site evaluations to determine the most appropriate safety interventions for each specific context. The PedISI framework, although widely adopted, is not the only one framework used to assess pedestrian safety. Micro-level pedestrian safety audits that have a strong connection to the safe system approach have been adopted by European and East Asian countries (Fitzpatrick et al., 2024; Kwon et al., 2022; Rastogi et al., 2011). Unlike PedISI, which assesses roadway design and traffic characteristics to improve pedestrian crossing facilities, a safe system approach focuses on forgiving road environments and reducing kinetic energy at points of conflict. However, this approach requires an extensive behavioral.

The PedISI framework has been used in many countries and contexts. Avinash et al. (2019) and Zhang et al. (2019) investigated the pedestrian crossing safety index by developing a multiple linear regression model to identify the factors influencing pedestrian safety. Their findings revealed that the minimum pedestrian safety margin when crossing a roadway depends on parameters such as pedestrian speed, vehicle distance, vehicle speed, pedestrian age, platoon size, pedestrian rolling behavior, vehicle type, and driver yielding behavior. Although previous studies primarily implemented the PedISI framework in a developed-country context, PedISI has been implemented in developed-country context with different traffic characteristics such as in Brazil (Pietrantonio and Fernando Bizerril Tourinho, 2006) and Indonesia. Studies by Fitriadi (2020) and Al Rasyid (2020) examined pedestrian crossing safety in Bandung City, Indonesia. Their findings revealed several influential variables, including land use type, crosswalk markings, leg width, availability of traffic signals, and daily traffic volume.

In contrast to previous studies that focused on both four-legs signalized and unsignalized intersections and incorporated user behaviour characteristics as independent variables, this research concentrates specifically on unsignalized three-leg intersections with data focused on pedestrian / user's perception rather on collecting behavioural data. User perception data offer several advantages (Ihssian and Ismail, 2023) over behavioral or accident-based data in pedestrian safety analysis (da Costa et al., 2016). Most notably, perception data are easier to collect than accident records, which are often scarce or insufficient. While behaviour data, such as near miss accident can be obtained by conducting observation study, such methods are resource-intensive and may pose safety risks to researchers (Ogwude et al., 2025). In contrast, user perception data provide a safer and more efficient alternative while also capturing subjective assessments of risk (Zhang et al., 2019; Zhu et al., 2025). Grounded in risk perception theory, this approach reflects pedestrians' evaluation of potential danger, enabling analysis of geometric and traffic-related factors independent of actual crash data, i.e., pedestrians may feel that crossing facilities are unsafe even if accident data show low figures (Avinash et al., 2019). Nevertheless, the challenge of using perception data to develop a pedestrian safety index model lies in the applicability of the model and its transferability to other sites (Zhu et al., 2025).

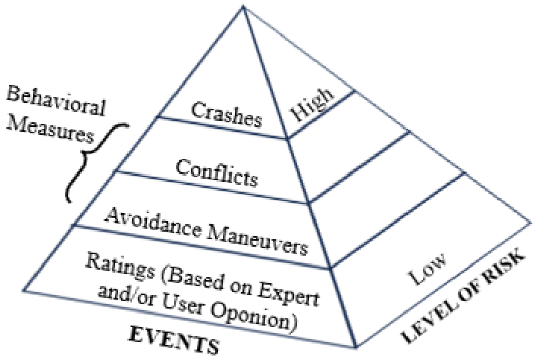

Figure 1. Safety index measurements

3 RESEARCH FRAMEWORK AND METHODOLOGY

The core framework of the PedISI model consists of four key steps for assessing pedestrian safety: crash data analysis, behavioral observations (including conflicts and evasive maneuvers), and expert or user-based evaluations. These elements are conceptualized within a safety assessment hierarchy often illustrated as a pyramid (see Figure 1). This paper specifically uses the low-risk approach using ratings based on user opinions. PedISI was developed using multiple linear regression analysis to establish a relationship between the dependent variable—namely, the average pedestrian safety score—and the numerical values of independent variables describing intersection geometry, pedestrian facilities, and traffic conditions.

This research follows four main steps (Figure 2): (1) Problem identification including questionnaire development based on literature reviews of previous studies dealing with PedISI frameworks; (2) Data collection including both secondary data and primary surveys such as a pilot survey; (3) Statistical tests for collected data; (4) PedISI model estimation and analysis including regression classical assumption tests and sensitivity analysis for policy implementation.

Data collection was conducted based on the identified factors that influence intersection safety. This data can be collected from previous research / official data (i.e. secondary data) or collected directly from the field (i.e. primary data). The list of data and the collection method are described in the next section. Following data collection, statistical data testing was conducted, including Cronbach's alpha reliability test and the Pearson correla-

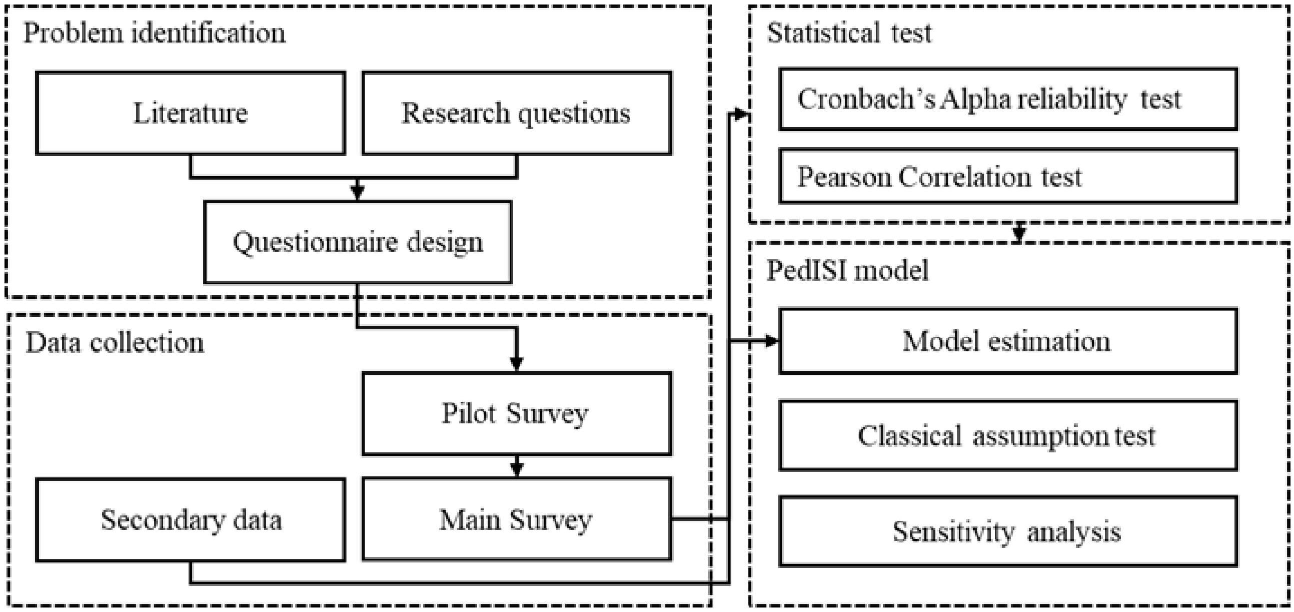

Figure 2. Research Framework

tion test. Cronbach's alpha reliability test evaluates whether multiple questionnaire items intended to measure the same general concept (e.g., safety perception, satisfaction, anxiety) do so reliably. In this paper, Cronbach's alpha is used to test the reliability of respondent perceptions of the pedestrian crossing safety index. Meanwhile, the Pearson correlation test is performed for all variables to analyze all variable correlations. The aim is to evaluate multicollinearity and to help select the most relevant independent variables that are significantly correlated with the dependent variable.

Lastly, the PedISI model is developed using the multiple linear regression method. The dependent variable (y) in the model is the average pedestrian safety rating provided by respondents, while the independent variables (x_i) include the physical characteristics of the intersection and traffic characteristics at the location. The a and b coefficients need to be estimated. The multiple linear regression can be mathematically expressed as shown in Equation 1.

$$y = a + b_1 x_1 + \dots + b_i x_i \tag{1}$$

Before applying the model to the study locations, the classical assumption test for regression is conducted. The aim is to make sure the estimated coefficients are unbiased, valid, and dependable. After the regression model is estimated and tested, the safety level of each leg of the intersection is calculated. This study utilizes the principle that the lower the safety score of a location, the higher its priority for evaluation. This is due to the greater potential danger faced by pedestrians at such locations. By assessing locations with low safety ratings, it becomes possible to identify the contributing factors to the high crash risk and to develop appropriate strategies to improve pedestrian safety.

4 CASE STUDY

This paper takes the three-leg intersections in the city of Cimahi as a case study. Cimahi has many three-leg intersections across the city and more importantly these intersections are unsignalized. Therefore, it is the ideal case study to obtain enough three-leg intersection facilities as a sample to build user perception data on the pedestrian crossing safety index based on different characteristics of the intersections. The approach of using user perceptions and the method for developing the pedestrian safety index model can be useful for replication in other locations, particularly if a post-analysis test of the regression model is conducted to examine its generalizability and predictive power.

In total, fourteen three-leg intersections, in which 42 pedestrian crossing facilities are evaluated (see Figure 3). The following are the criteria for the important conditions of unsignalized intersections that underlie the pedestrian safety problems in Cimahi City, (1) number of intersection legs (3 legs), (2) number of lanes per direction (1, 2, and 3 lanes) (3) availability of traffic signals, (4) presence or absence of zebra crossings, (5) type of land use around the site, (6) presence or absence of a median.

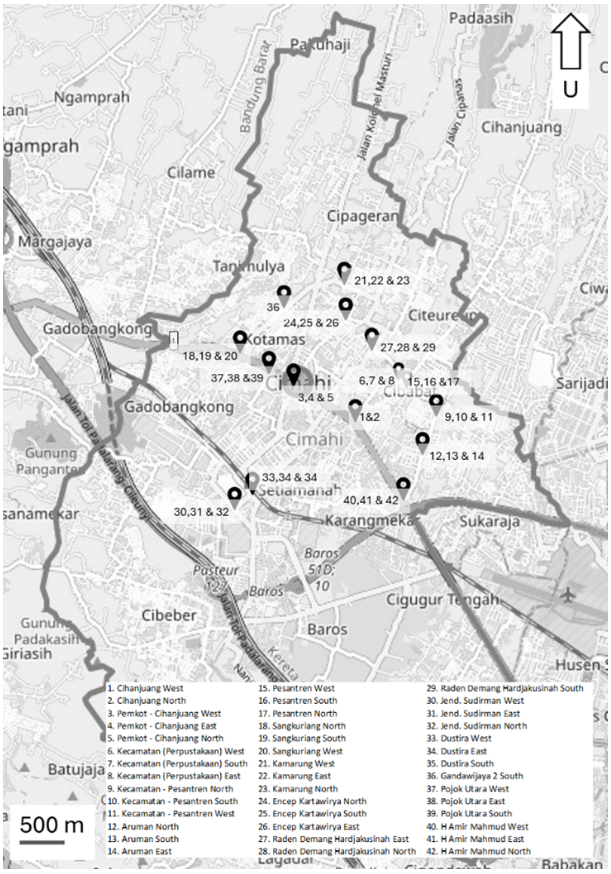

Figure 3. Three leg Intersection Study Location (source: google map)

5 SURVEY AND DATA COLLECTION

In this paper, 11 variables are considered for developing the PedISI model. In total, there are three data categories that need to be collected to develop the PedISI model: (1) Road geometry (2), traffic characteristics (3), and crossing safety index. The variables considered and the data collection methods are described in Table 1.

The crossing safety index is collected through a questionnaire survey. The index uses a Likert scale system, where a value of 1 indicates a very safe pedestrian crossing and a value of 5 indicates a very unsafe pedestrian crossing. Fourteen questionnaires were prepared, representing fourteen three-legged intersection locations across Cimahi and thus in total forty-two pedestrian crossing facilities were investigated. In each of these locations, at least 30 respondents were gathered to assess the safety of the intersection. The location and the number of respondents for each location can be seen in Table 2.

Table 1. Data requirement and collection method

No	Variable	Collection Method	Description
1	Pedestrian Crossing safety index	Questionnaire	Scale 1 (Very Safe) - 5 (Very Unsafe)
2	Traffic volume	Traffic counting	Vehicle/hour
3	85th percentile speed	Speed Gun	km/hour
4	Lane width	Wheel meter / Roll meter	meters
5	Number of lanes	Visual	1, 2, or 3
6	Maximum speed limit	Secondary data	30, 50, and 60 km hour^{-1}
7	Dominant land use type	Visual	0 = Non-commercial; 1 = Commercial
8	Markings availability	Visual	1 = Yes; 0 = No
9	Median width	Roll meter	meters
10	Presence of small alleys	Visual	1 = Yes; 0 = No
11	On-street parking	Visual	1 = Yes; 0 = No

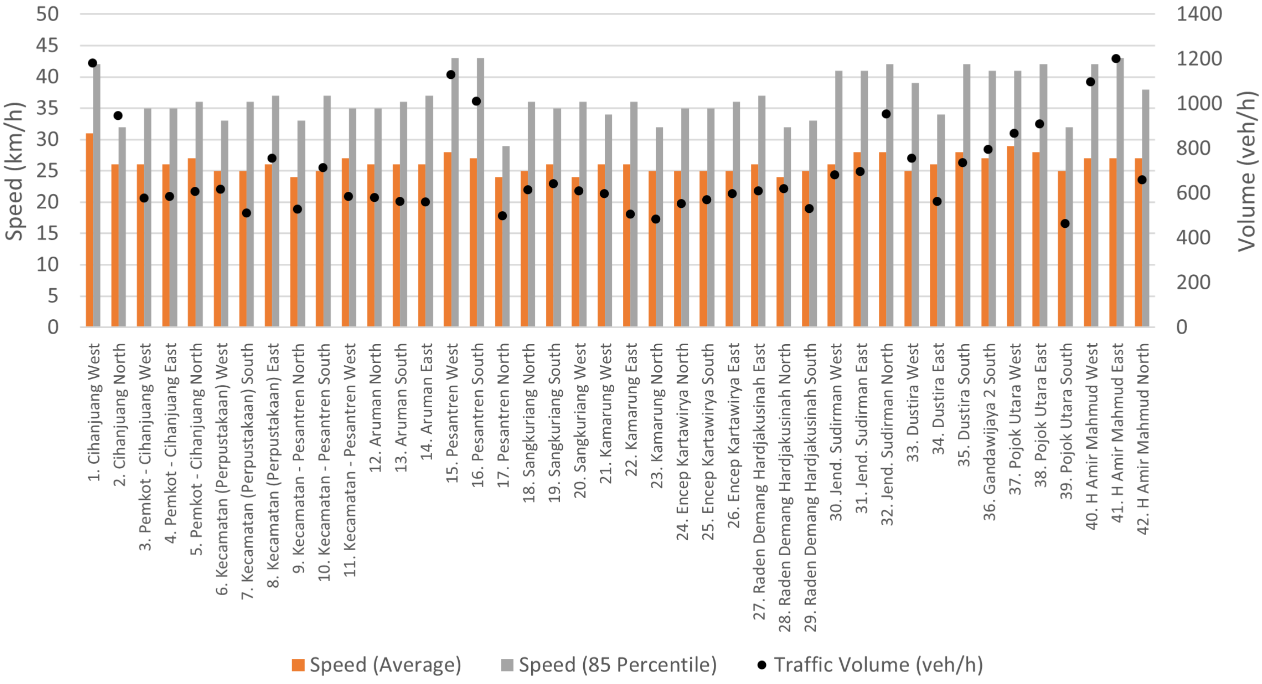

Figure 4. Resume of traffic volume and speed data

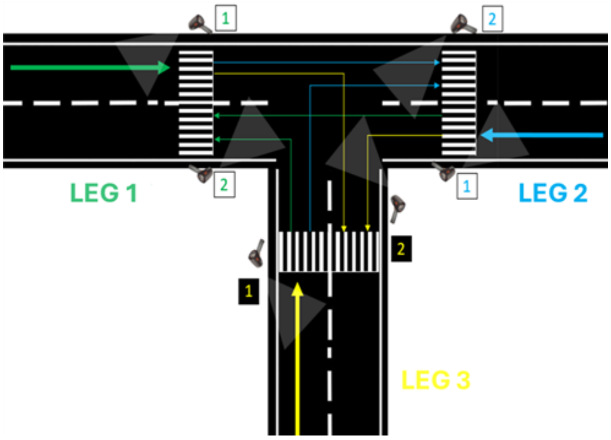

Figure 5. Speed and Traffic volume survey scheme

In the survey, the respondents answered questions regarding their perception of the safety index after watching a 60-second video visualising pedestrian crossing conditions and situations. To ensure valid responses, ratings were only allowed after the full video was viewed, and each respondent evaluated just one intersection to avoid fatigue. The video included actual pedestrian crossing the road to increase ecological validity of the responses given. Random sampling was used, but only Cimahi residents aged 17–55—capable of independent crossing—were included. A total of 623 respondents participated, with 72% aged 17–30 and 28% aged 30–55.

Regarding road geometric data, the data show that 66% of roads are 2-lane, 2-way undivided (2/2 UD), 14% are 4-lane, 2-way divided (4/2 D), 14% are 2-lane one-way (2/1 UD), and only 4% are 4-lane, 2-way undivided (4/2 UD), indicating that only 14% of roads have a median. Regarding lane width, 85% of roads have 2.5 m lanes, 14% have 3.5 m, and only 2% have 5 m lanes. Figure 4 shows summary of speed and traffic volume data at the 14 study locations. Traffic data, including volume and speed, were col-

Table 2. Number of observations for safety index data

No	Intersection	Leg	Respondent	Observation
1	Cihanjuang	West	41	41
2		North		41
3	Pemkot -	West	41	41
4	Cihanjuang	East		37
5		North		37
6	Kecamatan	West	37	37
7	(Perpustakaan)	South		32
8		East		32
9	Kecamatan -	North	41	32
10	Pesantren	South		41
11		West		41
12	Aruman	North	44	41
13		South		44
14		East		44
15	Pesantren	West	44	44
16		South		41
17		North		41
18	Sangkuriang	North	41	41
19		South		32
20		West		32
21	Kamarung	West	36	32
22		East		36
23		North		36
24	Encep Kartawirya	North	41	36
25		South		41
26		East		41
27	Raden Demang	East	41	41
28	Hardjakusumah	North		38
29		South		38
30	Jend. Sudirman	West	42	38
31		East		42
32		North		42
33	Dustira	West	44	42
34		East		44
35		South		44
36	Gandawijaya 2	South	44	44
37	Pojok Utara	West	42	42
38		East		42
39		South		
40	H Amir Mahmud	West	44	44
41		East		44
42		North		
	Total		623	1579

lected using a speed gun at unsaturated conditions near intersections, both for approaching and departing vehicles (see Figure 5). The speed data were then analysed based on the average and the 85th percentile.

6 RESULTS AND DISCUSSION

Firstly, we analyzed the respondents' answers to the safety rating using the Cronbach's Alpha reliability test for each respondent group. Table 3 presents the results of the data reliability test for each respondent group, where each group represents an intersection. The results show that all data sets have Cronbach's Alpha values (α) above 0.7, indicating high reliability. Next, Pearson correlation test was used to detect relationships among variables in the linear model. Variables with high correlation coefficients (greater than 0.8) were excluded from the model. Table 4 shows the results of the Pearson correlation. Variable X_4 has a high correlation with variables X_5 and X_8, and thus variable X_4 was eliminated from the model due to its strong correlation with two other independent variables.

Table 5 shows the results of the PedISI regression model. We conducted several iterations to ensure the best model for further analysis. The results reveal that pedestrian crossing safety is significantly influenced by traffic volume, vehicle speed, lane width, and median width. Across all five model iterations, three variables consistently showed strong and statistically significant effects: traffic volume (X_1), 85th percentile speed (X_2), and lane width (X_3). Higher traffic volume and vehicle speeds are associated with lower safety ratings, indicating that greater vehicle exposure and speed pose increased risks to pedestrians. Similarly, wider lanes tend to reduce safety perception, likely due to longer crossing distances and the possibility of vehicles traveling faster in wider lanes. Conversely, median width (X_8) was a significant positive contributor to safety perception among respondents in the model. A wider median improves pedestrian safety by offering a safe waiting zone, especially on multi-lane roads. Other variables—such as speed limit signage, on-street parking, and land use—were found to be statistically insignificant and were gradually removed to refine the model.

These findings align with previous studies on mid-block and three-leg pedestrian crossings, which concluded that vehicle speed, traffic volume, and road geometric consistency significantly influence pedestrian crossing safety (Avinash et al., 2019; da Costa et al., 2016). This consistency arises from similar conditions in which pedestrians must cross without signalized aid, such as pelican crossings. In such cases, unlike signalized intersections where delays are the primary factors influencing pedestrian crossing behavior and thus safety, at unsignalized facilities pedestrian safety is more affected by traffic volume and speed (Hashemi et al., 2022).

The regression model was developed iteratively, with attention to the model's goodness of fit, the predictive power of the model, and the significance of the estimated coefficients. The goodness of fit of a regression model evaluates how well the model estimates actual values. Statistically, it can be assessed through the coefficient of determination (R^2) and the F-statistic. The predictive power of the model is evaluated using the Root Mean Square Error between the data and the predictive value of the model. Meanwhile, the statistical significance of the independent variables' estimated parameters is evaluated using the t-test or p-values (Ghozali, 2018).

Table 3. Cronbach's Alpha Reliability Test Results

Set	Cronbach's α	N observation	Description	Set	Cronbach's α	N observation	Description
1	0.789	36	High Reliability	8	0.949	32	High Reliability
2	0.896	42	High Reliability	9	0.877	44	High Reliability
3	0.753	32	High Reliability	10	0.783	41	High Reliability
4	0.707	32	High Reliability	11	0.900	42	High Reliability
5	0.841	41	High Reliability	12	0.841	41	High Reliability
6	0.653	42	Medium Reliability	13	0.805	37	High Reliability
7	0.931	38	High Reliability	14	0.852	41	High Reliability

Table 4. Results for Pearson Correlation Test

	Y	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y	1										
X_1	-0.796	1									
X_2	-0.81	0.769	1								
X_3	-0.409	0.266	0.262	1							
X_4	-0.535	0.739	0.622	0.203	1						
X_5	-0.526	0.718	0.53	0.322	0.83	1					
X_6	-0.358	0.398	0.185	0.358	0.42	0.513	1				
X_7	0.452	-0.461	-0.478	-0.096	-0.341	-0.406	-0.028	1			
X_8	-0.442	0.701	0.524	0.195	0.842	0.662	0.354	-0.218	1		
X_9	0.024	-0.036	-0.106	0.004	-0.086	0.085	0.102	0.069	0.000	1	
X_{10}	0.178	-0.171	-0.187	0.339	-0.025	-0.077	0.216	0.059	0.028	-0.144	1

Table 5. Results for PedISI Regression Model

	Iteration 1		Iteration 2		Iteration 3		Iteration 4		Iteration 5	
	Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value
Constant	9.095	0.000	9.052	0.000	9.401	0.000	9.526	0.000	9.496	0.000
X_1	-0.002	0.006	-0.002	0.006	-0.002	0.003	-0.002	0.004	-0.002	0.000
X_2	-0.100	0.001	-0.099	0.001	-0.104	0.001	-0.104	0.001	-0.100	0.001
X_3	-0.414	0.027	-0.417	0.023	-0.402	0.027	-0.372	0.036	-0.355	0.024
X_5	0.010	0.231	0.009	0.235	0.008	0.313	-	-	-	-
X_6	-0.253	0.137	-0.259	0.122	-0.227	0.158	-0.175	0.248	-	-
X_7	0.126	0.434	0.126	0.430	-	-	-	-	-	-
X_8	0.664	0.255	0.658	0.253	0.780	0.159	0.965	0.067	1.021	0.028
X_9	-0.048	0.732	-	-	-	-	-	-	-	-
X_{10}	0.271	0.229	0.287	0.188	0.254	0.231	0.218	0.295	-	-
Adjusted R^2	0.753		0.760		0.762		0.762		0.761	
RMSE	0.354		0.355		0.358		0.363		0.374	
F-test	14.914		17.223		19.802		22.896		33.696	
N	42		42		42		42		42	
Y:	Pedestrian crossing safety rating									
X_1:	Traffic Volume (vehicle/h)				X_6:	Dummy for land use, 1 if commercial otherwise 0				
X_2:	85 percentile Speed (Kph)				X_7:	Dummy for road marking, 1 if any otherwise 0				
X_3:	Lane width (m)				X_8:	Median width (m)				
X_4:	Number of lane				X_9:	Dummy for small alley at intersection, 1 if any otherwise				
X_5:	Max Speed Limit (Kph)				X_{10}:	Dummy for on street parking, 1 if any otherwise 0				

The regression analysis of the collected pedestrian crossing perception data in this study demonstrates that the model has strong predictive power, explaining 75–76% of the variance in pedestrian safety ratings across sites, with only a modest increase in prediction error as the model is simplified. The final model, with only four significant predictors, provides the best balance between model simplicity and explanatory power (Adjusted R^2 = 0.761, RMSE = 0.374). Despite using fewer variables, the final model remains statistically robust and nearly as accurate, making it effective for comparing and predicting safety across different urban crossing sites. These statistical test results for the model show that while perception data introduces subjectivity, it can be made predictive and generalizable if it is collected systematically, linked to real-world measurable features, and modeled using robust statistical methods.

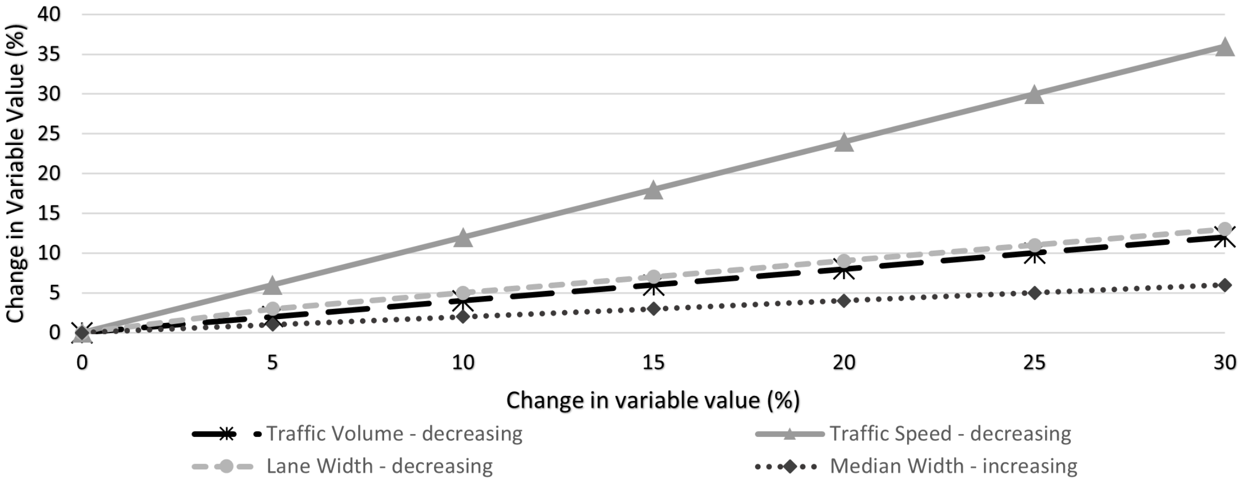

Figure 6. Sensitifity Analysis

Table 6. Heteroscedasticity Test and Multicollineraity test Results

No	Variabel	Glejser p-value	VIF value
1	X_1 = Traffic Volume	0.96537	3.547
2	X_2 = 85th Percentile Speed	0.07486	2.474
3	X_3 = Lane Width	0.71382	1.086
4	X_8 = Median Width	0.25193	1.989

To ensure external validation of the regression model, a cross-validation test was performed. Specifically, the Leave One Out Cross Validation (LOOCV) technique was employed, particularly due to the small data. LOOCV is a special case of k-fold cross-validation where k equals the number of observations (N) (Kuh et al., 2024). For this case, the LOOCV analysis ran 42 regressions, each time training the model on 41 observations and testing on the one that was left out. This process helps estimate how the model would perform on unseen data. The result showed a Root Mean Square Error ($RMSE$) of approximately 0.428. This means that, on average, the model's prediction of pedestrian crossing safety ratings was off by about 0.43 units (on the safety rating scale), when applied to unseen data (one site at a time). This is a relatively low error, considering that the rating scale, i.e. the independent variable, appears to range roughly between 1.6 to 4.8, indicating good generalizability. In summary, despite relying on subjective perception data, this study demonstrates that with systematic data collection and robust statistical methods, it is possible to develop a regression model with strong predictive power and generalizability.

Further, to ensure a robust ordinary least square (OLS) regression, classical assumption tests were conducted on the selected model. Classical assumption testing is a series of statistical tests conducted to ensure that a multiple linear regression model satisfies the underlying statistical assumptions. These assumptions are essential to guarantee the accuracy of the parameter estimates generated by the model (Nugroho et al., 2021)The classical assumption tests include: (1) Normality test, (2) Autocorrelation test, (3) Heteroscedasticity test, and (4) multicollinearity test.

The results of classical assumption tests are as follows:

- The normality test aims to determine whether the residuals are normally distributed. This test is conducted using a standard Kolmogorov-Smirnov test. The result of the normality test on the model residuals using the Kolmogorov-Smirnov test showed a significance value of 0.089. Since this value is greater than 0.05, it can be concluded that the residuals are normally distributed (Priyatno, 2009).
- Autocorrelation refers to a condition in a linear regression model where there is a dependency among the residuals (i.e., the differences between actual and predicted values) across successive observations. One common method to test for autocorrelation is the Durbin-Watson (DW) test. The DW value of our regression model is 2.077, which is greater than the lower bound d_u value of 1.720 and less than the upper bound value of 6.880. This result implies that there is no autocorrelation in the regression model.
- The heteroscedasticity test is conducted to examine whether there is a variance inequality in the residuals across observations in the regression model. If the residual variance remains constant across observations, the condition is called homoscedasticity; if it varies, it is referred to as heteroscedasticity. A good regression model is one that exhibits homoscedasticity or does not suffer from heteroscedasticity. The Glejser test is performed to test the heteroscedasticity of the model. Table 6 shows

  the heteroscedasticity test for regression independent variables using the Glejser test. The results show that all variables have p-values greater than 0.05, implying that there is no heteroscedasticity in the model.
- The multicollinearity test is conducted to detect the presence of high correlations among independent variables in a regression model. VIF is used to test multicollinearity in the regression model. VIF is the reciprocal of tolerance (i.e $VIF = \frac{1}{Tolerance}$), in which Tolerance is defined as $1 - R^2$, where R^2 is the coefficient of determination obtained by regressing one independent variable on all the others. Table 6 shows the VIF values, and the results show that the VIF value ranges between 1-5, which indicates moderate correlation but is usually acceptable (Priyatno, 2009).

Table 7. Results of Model Analysis of Road Crossing Safety Values in Cimahi City

No	Intersection	Leg Direction	X_1	X_2	X_3	X_8	Index
1	Cihanjuang	West	1182	39	4.1	0.5	1.92
2		North	945	36	3.3	0	2.60
3	Pemkot – Cihanjuang	West	578	36	3.5	0	3.29
4		East	585	37	3.5	0	3.25
5		North	607	37	4.5	0	2.82
6	Kecamatan (Perpustakaan)	West	616	35	3.5	0	3.36
7		South	509	36	4.0	0	3.26
8		East	756	38	3.5	0	2.69
9	Kecamatan – Pesantren	North	527	35	3.0	0	3.70
10		South	712	34	3.0	0	3.35
11		West	584	36	3.5	0	3.26
12	Aruman	North	579	36	3.0	0	3.45
13		South	561	36	3.0	0	3.49
14		East	559	36	3.5	0	3.32
15	Pesantren	West	1130	43	3.5	0.5	1.87
16		South	1009	42	3.5	0.5	2.26
17		North	499	34	3.5	0	3.72
18	Sangkuriang	North	614	36	4.0	0	3.02
19		South	642	36	4.0	0	3.02
20		West	610	36	4.0	0	3.02
21	Kamarung	West	598	35	3.0	0	3.58
22		East	505	36	3.0	0	3.71
23		North	484	36	2.5	0	3.94
24	Encep Kartawirya	North	552	39	3.0	0	3.24
25		South	570	37	3.0	0	3.46
26		East	533	36	2.5	0	3.74
27	Raden Demang Hardjakusinah	East	607	37	3.5	0.5	3.61
28		North	620	36	3.0	0	3.44
29		South	529	38	3.0	0	3.39
30	Jend. Sudirman	West	681	42	3.5	0	2.52
31		East	696	42	3.5	0	2.48
32		North	954	43	3.0	0	1.88
33	Dustira	Barat	756	42	3.5	0	2.34
34		East	563	36	3.5	0	3.31
35		South	736	43	3.0	0	2.48
36	Gandawijaya 2	South	794	41	3.8	0	2.25
37	Pojok Utara	West	867	42	3.5	0	2.08
38		East	908	43	3.5	0	1.90
39		South	462	39	3.0	0	3.46
40	H Amir Mahmud	West	1098	40	3.5	0.5	2.23
41		East	1201	40	3.5	0.5	1.99
42		North	658	39	4.0	0	2.66
Average							2.96
Standard Deviation							0.61

7 MODEL IMPLEMENTATION AND SENSITIVITY ANALYSIS

In this section, the regression equation is applied to calculate the pedestrian safety index at the study location. Generally, the results show that the three-legged intersections in Cimahi have adequate pedestrian crossing safety index with 83% of the locations studied having higher ratings above 2.5. However, there are seven locations where the index values are below 2.5 indicating safety risks for pedestrians. Table 7 shows the overall index value for all study locations. Jalan Raya Cibabat (west leg of Pesantren intersection) has the lowest safety index with pedestrian crossing safety index value of 2.20. This low safety index implies an urgent need to improve the situation at this location. The low index value is caused by the high value of 85th percentile speed in which reaches 43 km/h, the highest among the study location areas. In addition, Jalan Raya Cibabat Barat, which consists of four lanes, each with a lane length of 4 meters and a narrow median, has one of the highest traffic volumes in Cimahi City—reaching 1,130 vehicles per hour. These conditions create a hazardous crossing environment. Pedestrians must interact with high-speed vehicles over an extended period due to the long crossing distance.

Next, a sensitivity analysis was conducted by gradually adjusting the values of the independent variables and observing the resulting changes in the dependent variable. Each independent variable was modified by 5% from its initial value, while for locations without a median, the adjustment was made by increasing the width by 5% of the maximum median width. Figure 6 presents the results of the sensitivity analysis, in which the values of the independent variables were altered incrementally by 5%. The analysis shows that a reduction in the 85th percentile vehicle speed exhibits the highest sensitivity compared to changes in other independent variables. Specifically, each 5% reduction in the 85th percentile speed results in a 6% increase in the safety index of the pedestrian crossing location.

The results indicate that speedmanagement should be prioritized to improve perception of pedestrian safety, as reducing vehicle speed provides greater improvements than any other intervention. Efforts to reduce vehicle speed and enhance pedestrian safety through increased visibility and the provision of safe refuge areas can include the following measures: elevating the road's median, raising pedestrian crossing installing pedestrian crossing islands, and elevating intersection platforms. Additional speed-reducing treatments include rumble strips, speed tables, speed humps, chicanes (curved road alignments), and road narrowing (chokers or pinch points)—particularly in areas prone to crashes or with high pedestrian activity. Besides speed reduction, reducing vehicle volume is another strategy to improve the pedestrian safety index at intersections. This can be achieved by converting certain lanes into dedicated pedestrian, bicycle, or public transport lanes (e.g., BRT or other transit modes). Such interventions promote a shift toward public transportation, reduce private vehicle usage, and enhance safety and comfort for non-motorized road users.

Redesigning road geometry such as reducing lane width and increasing median width, can also contribute positively to improving safety. Nevertheless, these factors must be approached with caution. Lane width and median width are subject to road design standards that ensure road functionality and vehicle flow. Excessive narrowing of lanes may compromise vehicle maneuverability, and median expansion is only practical up to a reasonable limit—an excessively wide median (e.g., 100 m) would be infeasible and counterproductive in an urban context. Therefore, adjustments to lane and median widths should be considered only within the limits of established design standards.

8 CONCLUSIONS

The pedestrian safety index model for unsignalized three-leg intersections in Cimahi City is formulated based on regression analysis. The advancement of this study lies in its focus on unsignalized three-leg intersections, a junction type often overlooked in pedestrian safety research. Unlike typical mid-block or four-leg intersections, three-leg intersections present unique geometric and behavioral challenges due to asymmetric traffic patterns and irregular pedestrian paths. The use of a perception-based safety rating, derived from video stimuli and validated through rigorous statistical testing, offers a novel methodological approach that captures real-world pedestrian perception of the safety of pedestrian crossings. This approach bridges subjective safety perceptions with objective road characteristics, enabling more holistic and human-centered safety assessments.

The pedestrian safety index at 42 unsignalized three-leg intersections in Cimahi ranges from 1.5 to 4.5, with an average score of 3.17 and a standard deviation of 0.57. Accordingly, these values fall within the "moderately safe" category for pedestrian crossings. The analysis shows that traffic vehicle volumes, traffic speeds, lane width, and median width are significant factors affecting pedestrian crossing safety perceptions. Analyzing the model, the R^2 value of 0.78 indicates that the model explains 78% of the variation in safety index scores. This suggests that the model is sufficiently accurate in predicting safety levels based on vehicle volume, speed, lane width, and median width. The model also produces good predictive power, indicated by an RMSE value of 0.374. The strong predictive power and generalizability of the model make it a powerful tool for local governments to quantify and respond to public safety concerns, using predictions to prioritize significant interventions even in areas where direct perception surveys are not feasible. The model results align with previous studies, which found that traffic volume, traffic speed, lane width, and median width are significant factors for unsignalized crossing facilities (Rastogi et al., 2011; Zhu et al., 2025). From the sensitivity analysis, the 85th percentile speed was found to be the most influential variable compared to the other independent variables. Therefore, reducing vehicle speed is the most recommended strategy to improve pedestrian crossing safety. These findings support infrastructure-focused interventions such as lane narrowing, speed management, and median installation to enhance pedestrian safety particularly for three leg intersections facilities (da Costa et al., 2016).

This study has several limitations that should be acknowledged. First, traffic volume and speed data were collected only during the peak hour observation period, which may not fully capture daily or temporal variations in intersection conditions. Similarly, the video used to represent the intersections reflects only an ideal situation, recorded during calm daytime weather. Pedestrian perceptions may differ significantly under alternative conditions such as nighttime, rainfall, or other adverse environments. These limitations suggest that the ecological validity of the findings could be improved in future research. One promising approach is the use of virtual reality (VR) experiments to simulate diverse crossing environments and conditions, enabling the assessment of pedestrian perceptions under more realistic and varied scenarios. Future studies may also explicitly test the impact of safety measures—such as lane width reduction, stricter speed control, or median adjustments—using VR-based experimental designs. Additionally, incorporating individual pedestrian characteristics, such as trip purpose, age, and gender, alongside contextual conditions like weather and lighting, would provide a more comprehensive understanding of perception-based pedestrian safety.

DISCLAIMER

The authors declare no conflict of interest.

REFERENCES

Al Rasyid, W. O. V. (2020), Pengembangan model keselamatan penyeberangan jalan untuk simpang tiga lengan, Master thesis, Institut Teknologi Bandung, Bandung.

Avinash, C., Jiten, S., Arkatkar, S., Gaurang, J. and Manoranjan, P. (2019), ‘Evaluation of pedestrian safety margin at mid-block crosswalks in india’, *Safety Science* **119**, 188–198.
URL: *https://doi.org/10.1016/j.ssci.2018.12.009*

Center, e. a. (2007), Pedestrian and bicyclist interaction safety indices: user guide, Technical report, University of North Carolina, Highway Safety Research Center, McLean.

da Costa, J. O., Jacques, M. A. P., Soares, F. E. C. and Freitas, E. F. (2016), ‘Integration of geometric consistency contributory factors in three-leg junctions collision prediction models of portuguese two-lane national highways’, *Accident Analysis & Prevention* **86**, 59–67.
URL: *https://doi.org/10.1016/j.aap.2015.10.003*

Fitriadi, M. R. (2020), Pengembangan model keselamatan untuk penyeberangan pejalan kaki pada persimpangan di kota bandung (studi kasus: Simpang bersinyal dan tak bersinyal 4 lengan), Master thesis, Institut Teknologi Bandung, Bandung.

Fitzpatrick, K., Geedipally, S., Kutela, B. and Koonce, P. (2024), ‘Midblock pedestrian signal safety effectiveness’, *Transportation Research Record: Journal of the Transportation Research Board* **2678**(4), 243–256.
URL: *https://doi.org/10.1177/03611981231184196*

Gaikindo (2023), ‘Jumlah kendaraan di indonesia 147 juta unit, 60 persen di pulau jawa’, https://otomotif.kompas.com/read/2023/02/10/070200315/jumlah-kendaraan-di-indonesia-147-juta-unit-87-persen-motor.

Ghozali, I. (2018), *Aplikasi Analisis Multivariete Dengan Program IBM SPSS 25*, 9 edn, Badan Penerbit Universitas Diponegoro, Semarang.

Hashemi, H., Bargegol, I. and Hamedi, G. H. (2022), ‘Using logistic regression and point-biserial correlation, an investigation of pedestrian violations and their opportunities to cross at signalized intersections’, *IATSS Research* **46**(3), 388–397.
URL: *https://doi.org/10.1016/j.iatssr.2022.05.002*

Ihssian, A. and Ismail, K. (2023), ‘Modelling pedestrian safety at urban intersections using user perception’, *Accident Analysis & Prevention* **180**, 106912.
URL: *https://doi.org/10.1016/j.aap.2022.106912*

Jaskiewicz, F. (2000), Pedestrian level of service based on trip quality, *in* ‘TRB Circular E-C019: Urban Street Symposium’, pp. G1–G14.

Kuh, S., Kennedy, L., Chen, Q. and Gelman, A. (2024), ‘Using leaveoneout cross validation (loo) in a multilevel regression and poststratification (mrp) workflow: A cautionary tale’, *Statistics in Medicine* **43**(5), 953–982.
URL: *https://doi.org/10.1002/sim.9964*

Kwon, J.-H., Kim, J., Kim, S. and Cho, G.-H. (2022), 'Pedestrians safety perception and crossing behaviors in narrow urban streets: An experimental study using immersive virtual reality technology', *Accident Analysis & Prevention* **174**, 106757.
URL: *https://doi.org/10.1016/j.aap.2022.106757*

Nugroho, T. S., Balijepalli, C. and Whiteing, A. (2021), 'Independent retailer restocking choices in urban goods movement and interaction effects with traditional markets', *Networks and Spatial Economics* **21**(4), 933–969.
URL: *https://doi.org/10.1007/s11067-021-09555-4*

Ogwude, I. C., Ogwude, U. S. and Balogun, S. B. (2025), 'Driver behavior in developing countries: evidence from modeling anger and aggression performance of nigerian drivers on inter-city trips', *Transportation Research Procedia* **82**, 3390–3413.
URL: *https://doi.org/10.1016/j.trpro.2024.12.087*

Pietrantonio, H. and Fernando Bizerril Tourinho, L. (2006), 'A decision-based criterion for selecting parameters in the evaluation of pedestrian safety problems with the traffic conflict analysis technique', *Transportation Planning and Technology* **29**(3), 183–216.
URL: *https://doi.org/10.1080/03081060600810923*

Priyatno, D. (2009), *SPSS Analisis korelasi, regresi, dan multivariate*, Gava Media, Yogyakarta.

Rastogi, R., Chandra, S., Vamsheedhar, J. and Das, V. R. (2011), 'Parametric study of pedestrian speeds at midblock crossings', *Journal of Urban Planning and Development* **137**(4), 381–389.
URL: *https://doi.org/10.1061/(ASCE)UP.1943-5444.0000083*

Xu, H., Zhang, K., Zheng, Q. and Yao, R. (2018), 'Multi level pedestrian signalisation at large four - leg roundabouts', *IET Intelligent Transport Systems* **12**(8), 838–850.
URL: *https://doi.org/10.1049/iet-its.2017.0155*

Zhang, C., Chen, F. and Wei, Y. (2019), 'Evaluation of pedestrian crossing behavior and safety at uncontrolled mid-block crosswalks with different numbers of lanes in china', *Accident Analysis & Prevention* **123**, 263–273.
URL: *https://doi.org/10.1016/j.aap.2018.12.002*

Zhu, M., Graham, D. J., Zhang, N., Wang, Z. and Sze, N. N. (2025), 'Influences of weather on pedestrian safety perception at mid-block crossing: A cave-based study', *Accident Analysis & Prevention* **215**, 107988.
URL: *https://doi.org/10.1016/j.aap.2025.107988*