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Original Article

Evaluating the Effect of Stop Line Visibility on Driver Compliance at Urban Intersections in Jakarta

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Abstract

Urban intersections are critical nodes in city traffic systems, where road marking clarity is vital in guiding driver behavior and reducing violations. In rapidly growing cities such as Jakarta, the degradation of road markings, particularly stop line markings, poses a significant challenge to traffic safety and compliance. This study examines the influence of stop line marking clarity on road user compliance at urban intersections in Jakarta. The research applies a mixed-method approach that integrates field observation, speed profile analysis, Difference-in-Differences (DiD), and multiple linear regression to provide a comprehensive understanding of driver behavior. Two intersections representing different marking conditions, namely clear and faded markings, were selected as study locations. The DiD analysis shows a clear difference in violation behavior, where the intersection with clear markings has a violation rate of 22.0%, while the intersection with faded markings reaches 37.7%, resulting in a difference of 15.6%. The speed profile analysis indicates that vehicles at the intersection with faded markings maintain higher speeds at all observed distances. The largest difference occurs at 20 meters, with a speed gap of 4.74 km/h. This finding suggests that faded markings lead to delayed deceleration, while clear markings encourage earlier and more gradual speed reduction. The multiple linear regression proved that perceived marking clarity has a significant effect on violation behavior with a coefficient of 0.112 and a significance value of 0.029. The model explains 50.4% of the variation in violation behavior. Among the variables, ETLE awareness shows the strongest influence, followed by improved marking perception.

Keywords: Road User Compliance, Speed Profile, Stop Line Marking Clarity, Traffic Safety, Traffic Violations.

1. Introduction

In an effort to create a sustainable and well-ordered transportation system, the Provincial Government of DKI Jakarta has established a Green Transportation Hierarchy, which prioritizes pedestrians and cyclists, followed by public transport, shared mobility services, and private vehicles. The implementation of this policy requires not only disciplined road user behavior but also supportive traffic infrastructure, one of which is the clarity of road markings at intersections, particularly stop line markings.

top line markings serve as a critical visual element indicating the boundary where vehicles must stop when traffic signals turn red. The visibility and quality of these markings have been shown to directly influence driver compliance at signalized intersections. Studies indicate that degraded or low-visibility markings lead to compensatory driving behaviors, impair drivers' ability to accurately estimate their distance to the stop line, and increase the likelihood of violations (Bosurgi et al., 2022; Kučina et al., 2025). Furthermore, the placement and design of stop lines interact with signal configuration to shape dilemma zones and stopping decisions, making marking clarity a foundational component of intersection safety

(Shepelev et al., 2018). However, many road users in Jakarta continue to violate these markings by stopping beyond the designated line, encroaching on pedestrian crossings, or running red lights. According to Law No. 22 of 2009 on Road Traffic and Transportation, Article 287 paragraph (1), violations of road markings are subject to penalties, including fines of up to IDR 500,000 or imprisonment. Nevertheless, law enforcement alone is insufficient if the road markings are not clearly visible to drivers.

Traffic violation data based on the Electronic Traffic Law Enforcement (ETLE) system in 2025 within the Polda Metro Jaya jurisdiction indicate that violations related to traffic signs and road markings, including stop line violations, remain relatively high compared to other types of violations. Based on the data, violations categorized as "sign/marking violations" increased significantly from 17,765 cases in September to 36,837 cases in November, before decreasing to 29,115 cases in December. Additionally, violations related to "running red lights" showed even higher figures, peaking at 49,979 cases in November. These findings highlight that violations of visual traffic control elements, including stop line markings, continue to be a major issue in urban areas. This pattern is consistent with international evidence suggesting that ETLE systems, while effective in deterring violations, achieve maximum impact only when combined with clearly visible road markings and adequate infrastructure quality (Anggia et al., 2022; Asmara & Arimuladi, 2024).

The role of road marking quality extends beyond driver compliance and is closely linked to pedestrian safety outcomes. Poor visibility of stop lines and crosswalks has been associated with increased pedestrian signal violations and greater conflict risk at urban intersections (Mukherjee et al., 2025; Mukherjee & Mitra, 2020). Engineering interventions, such as LED-backlit stop signs and illuminated crosswalk markings, have demonstrated significant reductions in red-light violations and pedestrian conflicts, underscoring the safety value of investing in marking visibility (Hussain et al., 2020; Layegh et al., 2025). This phenomenon suggests that road user compliance with stop line markings is influenced not only by law enforcement but also by the quality and visibility of the markings themselves. Poorly visible markings, due to fading, low contrast, or reduced visibility at night, may hinder drivers' ability to accurately recognize stopping boundaries. As a result, violations such as stopping beyond the stop line or entering conflict zones become more frequent, increasing the risk of traffic accidents, particularly involving pedestrians at intersections.

Despite the growing body of literature on road marking quality and intersection safety, there remains a notable gap in empirical research that simultaneously examines marking clarity, driver compliance behavior, and enforcement effectiveness within a unified analytical framework, particularly in developing urban contexts such as Jakarta. Most existing studies address these factors in isolation or in high-income country settings, leaving the interplay between infrastructure condition, behavioral response, and enforcement outcomes underexplored in cities with mixed traffic and rapidly expanding road networks (Alimo et al., 2021; Patel et al., 2023). Therefore, this study aims to empirically analyze the effect of stop line marking clarity on road user compliance at urban intersections, specifically in DKI Jakarta. By integrating field observation data, ETLE violation data, and road user perceptions obtained through questionnaires, this research seeks to provide a comprehensive understanding of the relationship between marking quality and driver behavior. The findings of this study are expected to serve as a basis for recommendations to improve the design, placement, and maintenance of road markings in order to support a more effective and sustainable traffic safety system.

2. Literature Review

2.1. Traffic Accident Factors

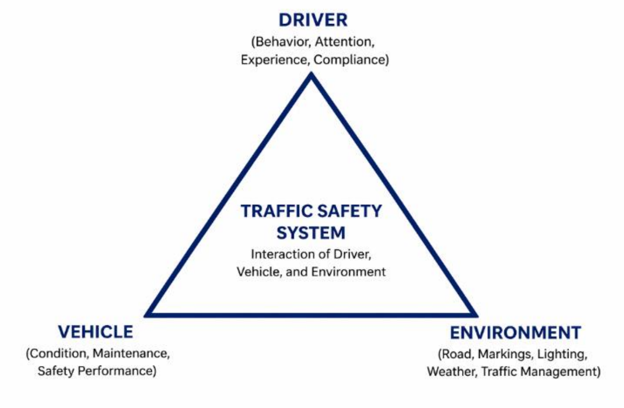

Figure 1. Traffic Accident Factors

Based on the figure 1, traffic safety is determined by three main components that interact with one another: the driver, the vehicle, and the environment. The driver factor includes driving skills, level of concentration, experience, physical and psychological conditions, as well as compliance with traffic regulations. Driver behavior is the key factor in maintaining road safety, as the majority of road incidents are caused by human error, such as lack of attention, poor decision-making, and non-compliance with traffic signs and road markings.

The vehicle factor relates to the technical condition and operational readiness of the vehicle. Components such as brakes, tires, lighting systems, steering, and regular maintenance significantly influence vehicle stability and the driver's ability to control speed and direction. Poorly maintained vehicles increase the risk of accidents, particularly in situations requiring rapid response to changing traffic conditions, such as sudden stops at intersections.

The environmental factor includes road conditions, weather, lighting, traffic management, and the presence of safety facilities such as traffic signs and road markings. Inadequate road environments, such as faded stop line markings, unclear pedestrian crossings, or poor lighting, can reduce driver compliance and increase the likelihood of traffic conflicts. Therefore, maintaining a balance among these three factors is essential to achieving a safe traffic system. A deficiency in any one factor can significantly increase accident risk, making a comprehensive understanding of their interaction crucial for traffic safety analysis, particularly in intersection areas.

2.2. Likert Scale

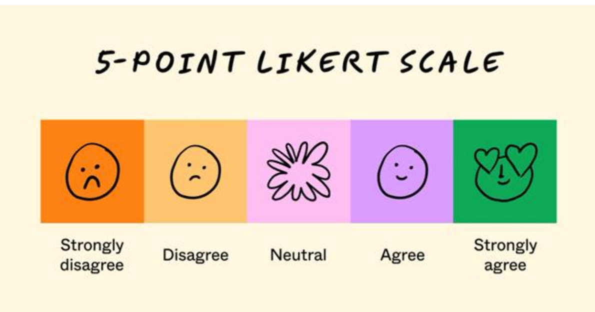

Figure 2. Likert Scale

The Likert scale as depicted in figure 2 is one of the most widely used methods for measuring perceptions in social research due to its ability to transform subjective responses into quantitative data that can be easily analyzed. This concept was first introduced by Rensis Likert and has since evolved into a standard instrument for measuring attitudes, opinions, and behavioral tendencies. In its application, respondents are asked to evaluate a statement using a series of response options arranged from the highest level of disagreement to the highest level of agreement. According to Binus University, the use of numerically structured response options enables researchers to systematically capture the intensity of respondents' views, allowing qualitative perceptions to be analyzed using statistical methods.

The Likert scale is commonly presented in five to seven levels, with a midpoint option representing a neutral response. The flexibility in the number of scale points allows researchers to tailor the instrument to the characteristics of the study and respondents. As highlighted in the Binus reference, this design helps respondents select answers that best reflect their opinions without feeling forced toward a particular stance. Further, the structured nature of the scale enables researchers to analyze response trends, assess consistency across items, and examine relationships between variables using statistical techniques such as linear regression, mean comparison, and correlation analysis. Thus, the Likert scale serves as an effective bridge between qualitative perceptions and quantitative analysis.

However, the use of the Likert scale also has limitations, particularly the potential for response bias, such as the tendency of respondents to select neutral or avoid extreme options. This may affect the accuracy of interpretation if the questionnaire items are not carefully constructed. Therefore, as emphasized by Binus University, the design of statements must be conducted rigorously to ensure they accurately represent the constructs being measured. In the context of this study on drivers' perceptions of stop line marking clarity, the Likert scale is highly appropriate as it captures variations in road user assessments in a structured manner. The resulting scores can then be used to evaluate compliance tendencies, identify factors influencing perception, and analyze the relationship between marking conditions and driver behavior using appropriate statistical methods.

2.3. Difference-In-Differences

Difference-in-Differences (DiD) is a widely used quasi-experimental method for evaluating the impact of an intervention or policy by comparing changes in outcomes between a treatment group and a comparison group before and after the intervention. This method is commonly applied in economics and public policy research due to its ability to control for external factors that vary over time, making the estimated intervention effect more robust than a simple before–after approach. Studies by Angrist and Pischke (2009) and Goodman-Bacon (2021) highlight DiD as one of the primary approaches for causal inference when randomized experiments are not feasible.

Conceptually, DiD works by calculating the change in outcomes for the treatment group and then subtracting the change observed in the control group. In this way, the net effect of the intervention can be isolated from general trends affecting both groups. In practice, this approach is typically estimated using a regression model that includes dummy variables for the treatment group, time period, and their interaction, where the interaction coefficient represents the effect of the intervention. This method has been further developed in recent studies, such as Callaway and Sant'Anna (2021), which emphasize the importance of accounting for treatment timing variation and heterogeneous effects.

A key assumption of the DiD method is the parallel trends assumption, which states that prior to the intervention, the outcome trends of the treatment and control groups move in parallel. If this assumption holds, then any divergence in trends after the intervention can be attributed to the treatment effect. Recent literature, such as De Chaisemartin and d'Haultfoeuille (2020), underscores that the validity of DiD relies heavily on the proper selection of control groups and the consistency of pre-treatment trends.

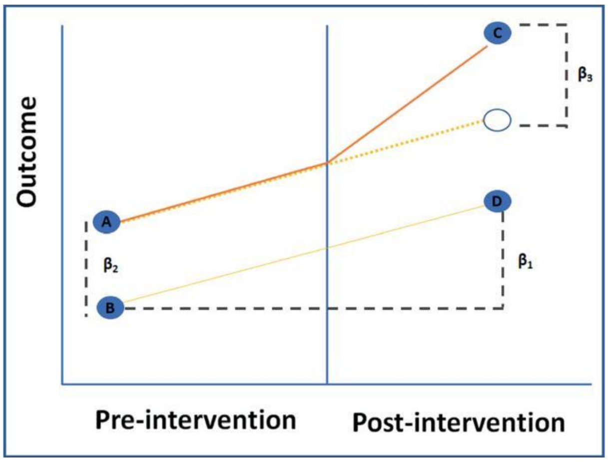

Figure 3. DiD Illustration
Source: Connor et al. (2023)

Figure 3 above illustrates the basic concept of the Difference-in-Differences (DiD) approach used to measure the impact of an intervention by comparing changes in outcomes between the treatment group and the control group before and after the intervention. On the left side of the graph, points A and B represent the initial conditions of the two groups, namely the treatment group and the control group. The difference between these two points is denoted by β2, which reflects the baseline difference between the groups prior to the intervention. On the right side of the graph, points C and D indicate the conditions after the intervention, with the difference between them represented by β1.

The dashed line extending from point A to the hypothetical point on the right side illustrates the expected outcome for the treatment group in the absence of the intervention. The difference between the actual observed point C and this hypothetical point is denoted by β3, which represents the estimated treatment effect. Therefore, the DiD approach does not merely capture the simple before-after change, but also adjusts for trends observed in the control group, resulting in a more accurate estimation of the intervention's impact.

2.4. Multiple Linear Regression

Multiple linear regression is a statistical analysis technique used when a researcher aims to examine the effect of more than one independent variable on a single dependent variable. The general form of the model can be expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + e \quad (1)$$

where Y represents the dependent variable, $X_1, X_2, ..., X_n$ are the independent variables, β_0 is the intercept, $\beta_1, \beta_2, ..., \beta_n$ are the regression coefficients indicating the magnitude and direction of the influence of each independent variable, and e represents the error term or residual, capturing the effects of other variables not included in the model.

In research practice, multiple linear regression allows researchers to understand not only the individual effect of each independent variable on the dependent variable but also how these variables jointly influence the outcome. As highlighted in academic sources such as Binus University, this method enables the evaluation of the combined effect of multiple independent variables and the direction of their relationships (positive or negative). In addition, the coefficient of determination (R^2) is used to assess how well the independent variables collectively explain the variability of the dependent variable. The closer the R^2 value is to 1, the greater the proportion of variance explained by the model.

However, the application of multiple linear regression requires several classical assumptions to ensure the validity and reliability of the results. These assumptions include linearity between independent and dependent variables, normal distribution of residuals, homoscedasticity (constant variance of errors), absence of multicollinearity among independent variables, and absence of autocorrelation (particularly for time series data). If these assumptions are violated, the estimated regression coefficients may become biased or misleading.

In the context of this study, multiple linear regression is used to analyze the effect of stop line marking clarity on road user compliance at urban intersections. This method is particularly relevant as it allows the inclusion of multiple control variables such as nighttime visibility, traffic density, and law enforcement perception and enables the assessment of the independent effect of each variable within an integrated analytical framework.

3. Methods

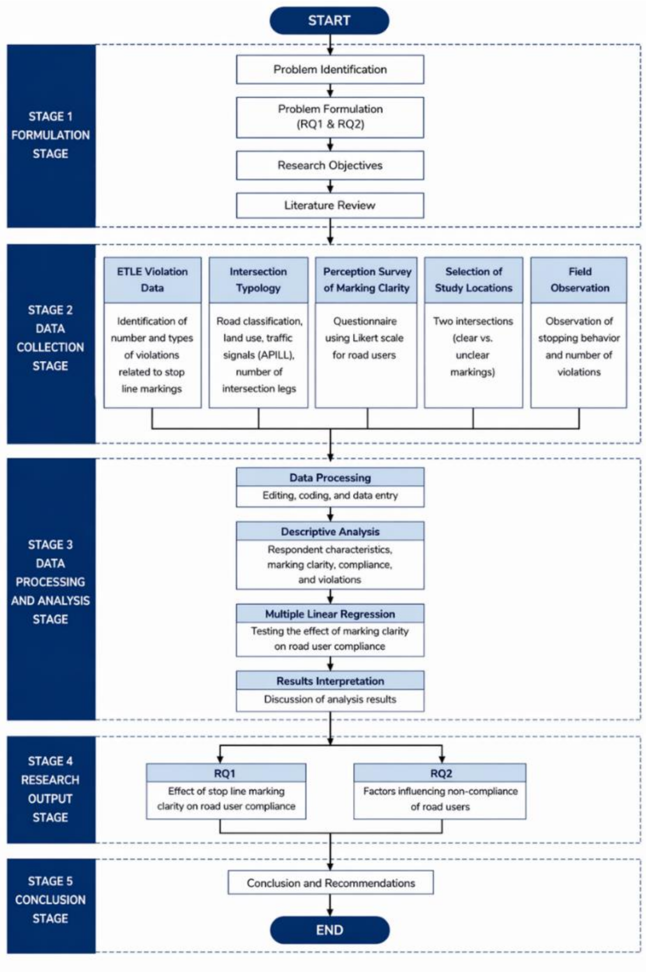

Figure 4. Research Flowchart

Based on the flowchart depicted in figure 4, this study was conducted systematically through a series of integrated stages to address two main research questions (RQ) related to road user compliance with stop line markings at urban intersections in DKI Jakarta. The initial stage began with problem identification, highlighting the high rate of violations related to road markings, particularly stop lines. This issue was then formulated into research problems divided into RQ1 and RQ2, followed by the establishment of research objectives. A literature review was subsequently conducted to provide a strong theoretical foundation and support the analytical framework of the study.

The next stage involved comprehensive data collection using multiple approaches. First, ETLE-based violation data were analyzed to identify the dominant types and frequencies of violations. Second, intersection typologies were classified based on characteristics such as road class, land use function, the presence of traffic signals (APILL), and the number of intersection legs. Third, a perception survey on marking clarity was conducted using a Likert-scale questionnaire to capture road users' evaluations of stop line conditions. Based on these results, two intersection locations were selected to represent different marking conditions, namely clear and unclear markings. Subsequently, field observations were carried out to directly measure road user compliance and the number of violations occurring at each location.

The following stage consisted of data processing and analysis. The collected data underwent editing, coding, and data entry procedures. Initial analysis was conducted descriptively to illustrate respondent characteristics, marking conditions, and levels of compliance and violations. This was followed by multiple linear regression analysis to examine the effect of stop line marking clarity on road user compliance. In addition, further analysis was conducted to identify the key factors contributing to non-compliance based on both observational data and user perceptions.

In the results stage, findings were obtained to answer RQ1, namely the magnitude of the effect of marking clarity on road user compliance, and RQ2, which identifies the dominant factors contributing to non-compliance. All findings were then synthesized into conclusions and recommendations, which are expected to serve as a basis for improving the design, placement, and maintenance of road markings in order to enhance traffic safety at urban intersections.

3.1. Intersection Selection

At the initial stage of data collection, an online questionnaire was distributed to road users in the DKI Jakarta area. This stage aimed to identify road users' perceptions regarding the clarity of stop line markings at several candidate intersections selected for the study. Five intersections were initially defined as candidate locations, namely Mampang Intersection (toward Kuningan), Ragunan Intersection (toward Mampang), ASEAN Intersection (Jl. Trunojoyo, toward Kebayoran), Pondok Indah Intersection (Pondok Pinang toward Radio Dalam), and Pondok Indah Intersection (Radio Dalam toward Pondok Pinang).

Respondents were asked to evaluate intersections they had previously passed through. Each respondent was allowed to assess more than one intersection, enabling the data to reflect variations in perception across different locations. To ensure the reliability of responses, respondents were also required to indicate their travel frequency at each intersection. This approach ensured that the evaluations were based on actual user experience and familiarity with the intersection conditions.

The clarity of stop line markings was assessed using several key indicators, including visibility of the stop line from the driver's perspective, contrast between the marking and the road surface, line thickness, visibility under nighttime or rainy conditions, position of the stop line relative to the pedestrian crossing, and the effectiveness of the marking in guiding drivers to stop at the correct position.

All indicators were measured using a Likert scale ranging from 1 to 5. The questionnaire results were analyzed by calculating the average perception score of marking clarity for each intersection. Based on this analysis, the ranking of stop line marking clarity across the five intersections was obtained.

Table 1. Intersection Ranking

No	Intersection	Average Score	Ranking
1.	Mampang Intersection (toward Kuningan)	3.153	2
2.	Ragunan Intersection (toward Mampang)	3.512	3
3.	ASEAN Intersection (Jl. Trunojoyo, toward Kebayoran)	4.173	5
4.	Pondok Indah (Pondok Pinang toward Radio Dalam)	3.938	4
5.	Pondok Indah (Radio Dalam toward Pondok Pinang)	2.704	1

The results summarized in table 1 indicate that the intersection with the highest level of marking clarity is the ASEAN Intersection (Jl. Trunojoyo, toward Kebayoran), with an average score of 4.173. In contrast, the intersection with the lowest level of marking clarity is the Pondok Indah Intersection (Radio Dalam toward Pondok Pinang), with an average score of 2.704. Based on these findings, the two intersections representing the highest and lowest levels of marking clarity were selected as the study locations for further analysis. This selection allows for a direct comparison between clear and unclear marking conditions, enabling a more comprehensive evaluation of their impact on road user compliance. Subsequently, field observations and on-site surveys were conducted at the selected intersections to validate the actual marking conditions and to capture real driver behavior in response to the stop line markings.

3.2. Difference-In-Differences

The analysis of road user behavior in this study was conducted through a structured observational approach using video recordings at selected intersections. The primary objective was to capture both compliance behavior and dynamic vehicle movement when approaching the stop line. The observations were carried out at two intersections representing different stop line marking conditions, namely clear markings and faded markings. The recorded videos were then analyzed frame-by-frame to ensure accurate measurement of both violation occurrences and vehicle movement patterns.

For the violation analysis, vehicles were classified based on their stopping position relative to the stop line marking. A vehicle was categorized as compliant if it stopped completely behind the stop line, while it was categorized as a violation if it stopped beyond or crossed the marking. The classification approach differs slightly based on vehicle type. For motorcycles, each rider positioned ahead of the stop line was counted as one violation, as each rider has an independent opportunity to comply or violate. In contrast, for passenger cars, only the leading vehicle in the queue was considered, as vehicles behind do not have the opportunity to violate until the front vehicle moves. The total number of observed vehicles, compliant vehicles, and violations were aggregated over the observation period to determine the overall compliance level and violation tendency at each intersection.

In addition to violation behavior, this study also analyzed vehicle speed profiles to understand how drivers adjust their speed when approaching the stop line. The speed analysis was conducted using travel time data extracted from the video recordings. Several observation points were defined at fixed distances from the stop line, specifically at 30 meters, 20 meters, 10 meters, and at the stop line itself (0 meters). The time taken by each vehicle to travel between these points was measured, allowing the calculation of vehicle speed using the basic relationship between distance and time. The resulting speed values were then converted into kilometers per hour (km/h) to ensure consistency and comparability.

To improve reliability, the calculated speeds were averaged across multiple vehicles at each observation point, resulting in representative speed values for each distance. This method allows the identification of deceleration patterns as vehicles approach the intersection. By comparing speed values at different distances, the study is able to determine how early drivers begin to reduce speed and how gradually they decelerate. These patterns are essential for understanding the behavioral response of drivers to different stop line marking conditions.

The combination of violation analysis and speed profile analysis provides a comprehensive evaluation of driver behavior. The violation analysis captures the final stopping outcome (whether drivers comply or violate), while the speed profile analysis reveals the process leading to that outcome, particularly how drivers adjust their speed when approaching the stop line. By integrating these two analytical approaches, the study is able to assess not only the level of compliance but also the underlying behavioral mechanisms influenced by the clarity of stop line markings.

3.3. Multiple Linear Regression

To examine the relationship between stop line marking clarity and road user compliance, this study employs a multiple linear regression approach. This method is used to analyze the simultaneous effect of several independent variables on a single dependent variable, allowing the study to capture the relative contribution of each factor in influencing driver behavior.

In this study, the dependent variable represents road user compliance, which is operationalized as a binary outcome indicating whether a driver violates the stop line or not. The independent variables include perceived clarity of stop line markings, driver behavior and compliance tendency, perceived law enforcement, and awareness of traffic monitoring systems such as ETLE. These variables are derived from questionnaire responses measured using a Likert scale, which are treated as interval data to enable parametric statistical analysis. The regression model is expressed in the general form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \varepsilon$$

where Y represents road user compliance, X_1 represents perceived marking clarity, X_2represents driver behavior, X_3represents perceived law enforcement, and X_4 represents ETLE awareness. The term $\beta_0$denotes the intercept, while $\beta_1$to β_4 represent the regression coefficients that indicate the magnitude and direction of influence of each independent variable. The error term εcaptures other unobserved factors affecting compliance.

Prior to model estimation, the data undergo preprocessing, including coding of responses, aggregation of Likert-scale items into composite variables, and validation of data consistency. The regression analysis is then performed to estimate the coefficients and assess the significance of each independent variable. Statistical indicators such as the coefficient of determination (R^2) are used to evaluate how well the independent variables explain the variation in the dependent variable, while significance tests (p-values) are used to determine whether the observed relationships are statistically meaningful.

To ensure the validity of the regression results, several classical assumptions are considered, including linearity of relationships, normal distribution of residuals, homoscedasticity, and absence of multicollinearity among independent variables. Although the dependent variable is binary, the use of multiple linear regression in this study is intended to explore the direction and relative strength of relationships between variables, which remains a common practice in exploratory behavioral studies.

Overall, the multiple linear regression method enables a comprehensive assessment of how different perception and behavioral factors influence road user compliance, providing a quantitative basis for understanding the role of stop line marking clarity in shaping driver behavior at urban intersections.

4. Results and Discussion

4.1. Violation Difference-In-Differences

The analysis of traffic violations in this study was conducted through direct field observation using video recordings at selected intersections. Vehicles were counted and classified based on their stopping position relative to the stop line marking. A vehicle was categorized as compliant if it stopped behind the stop line, and as a violation if it stopped beyond or crossed the stop line. For motorcycles, each rider positioned ahead of the stop line was counted as one violation, as each rider has an independent opportunity to comply or violate. For passenger cars, only vehicles positioned at the front of the queue were considered in the analysis, since vehicles behind do not have a direct opportunity to violate the stop line until the leading vehicle moves. The total number of observed vehicles, compliant vehicles, and violations were then aggregated to calculate the percentage of violations at each intersection.

Table 2. Violation DiD

Intersection	Marking Clarity	Violation Rate
ASEAN Intersection (Jl. Trunojoyo, toward Kebayoran)	High	22.00%
Pondok Indah (Radio Dalam toward Pondok Pinang)	Low	37.70%
Difference (DiD)	-	15.60%

The results of the observation shown in table 2 indicate that the violation rate at the ASEAN Intersection (Jl. Trunojoyo, toward Kebayoran), which represents a condition with clear stop line markings, is 22.0%. In contrast, the violation rate at the Pondok Indah Intersection (Radio Dalam toward Pondok Pinang), which represents a condition with faded markings, reaches 37.7%. This results in a difference of 15.6% between the two intersections.

This difference reflects a substantial variation in driver behavior between intersections with different levels of marking clarity. At the intersection with clearer markings, drivers tend to comply more consistently by stopping behind the stop line. Conversely, at the intersection with faded markings, the violation rate increases significantly, indicating reduced compliance.

Within the Difference-in-Differences (DiD) framework, this comparison can be interpreted as an indication that marking clarity contributes to differences in compliance behavior. Although no temporal intervention is applied, the comparison between two contrasting conditions (clear versus faded markings) serves as a quasi-experimental approach. This allows the observed difference to be interpreted as the effect of marking clarity on driver compliance.

In addition, the higher violation rate observed at the Pondok Indah Intersection may also be influenced by higher traffic volume, which increases congestion pressure and encourages drivers to violate the stop line. However, the magnitude of the difference suggests that marking clarity remains a key factor influencing road user behavior.

4.2. Speed Profile Difference-In-Differences

The analysis of vehicle speed was conducted using travel time data derived from video recordings of traffic flow at the study locations. Several observation points were established at distances of 30 meters, 20 meters, 10 meters, and 0 meters from the stop line. The time taken by each vehicle to travel between these points was recorded, and vehicle speed was calculated using the fundamental relationship between distance and time. The resulting speeds which summarized in table 3 were then averaged to obtain representative values at each observation point.

Table 3. Speed Profile DiD

Distance (m)	Clear Markings (ASEAN)	Faded Markings (Pondok Indah)
30	15.65	17.14
20	10.91	15.65
10	6.67	8.37
0	0.00	0.00

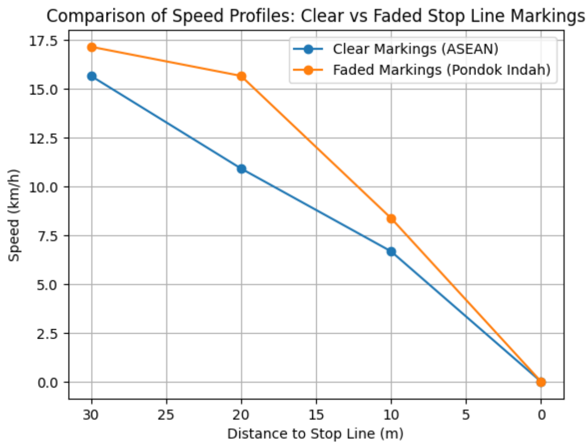

Figure 5. Comparison of Speed Profiles

The results shown in figure 5 indicate that vehicle speeds at the Pondok Indah Intersection (faded markings) are consistently higher than those at the ASEAN Intersection (clear markings) across all distances. The largest difference is observed at 20 meters, with a gap of 4.74 km/h. This suggests that under faded marking conditions, drivers tend to delay deceleration and maintain higher speeds until they are closer to the stop line. In contrast, at the ASEAN Intersection, where markings are clearer, speed reduction occurs earlier and more gradually. This indicates that clear markings provide an effective visual cue that prompts drivers to begin decelerating at a greater distance from the stop line.

The observed differences in speed behavior have direct implications for traffic safety. Under faded marking conditions, delayed deceleration results in more abrupt braking, which increases the risk of rear-end collisions, particularly under high traffic density. Additionally, vehicles approaching the stop line at higher speeds are more likely to cross the stop line, thereby increasing potential conflicts with pedestrians and cross traffic. Conversely, clear stop line markings encourage earlier and more controlled deceleration, allowing drivers sufficient time to respond to traffic signals and surrounding conditions. This smoother deceleration pattern reduces the likelihood of sudden braking and enhances overall vehicle control. Therefore, the findings indicate that stop line marking clarity not only affects compliance behavior but also plays a significant role in shaping safer speed behavior when approaching intersections. Improving marking clarity can serve as a simple yet effective intervention to enhance urban traffic safety.

4.3. Multiple Linear Regression Analysis

Table 4. Multiple Linear Regression Result

Variable	B	Std. Error	Beta	t-value	Sig.
Constant	0.513	0.269	–	1.903	0.059
Gender	0.081	0.063	0.080	1.279	0.203
Age	0.019	0.022	0.057	0.893	0.373
Vehicle Type	0.114	0.066	0.115	1.743	0.084
Travel Frequency	0.042	0.039	0.069	1.081	0.282
Trip Purpose	-0.025	0.041	-0.038	-0.598	0.551
Travel Time	-0.014	0.028	-0.031	-0.502	0.617
Perceived Marking Clarity	0.112	0.051	0.142	2.204	0.029
Driving Behavior	-0.048	0.065	-0.129	-0.745	0.457
Law Enforcement	0.038	0.064	0.103	0.592	0.555
ETLE Awareness	-0.475	0.076	-0.448	-6.275	0.000
Improved Marking Perception	-0.384	0.080	-0.334	-4.794	0.000

Table 4 summarized the results of the multiple linear regression analysis which indicate that the model has a relatively strong explanatory power, with an R value of 0.710 and an R^2 of 0.504. This suggests that 50.4% of the variation in violation behavior can be explained by the independent variables included in the model. Among all variables, perceived marking clarity emerges as one of the key factors influencing road user behavior, as it is statistically significant with a coefficient (B = 0.112) and a significance value of 0.029.

The significance of perceived marking clarity indicates that drivers' perception of how clear and visible the stop line markings are playing an important role in shaping their compliance behavior. This finding confirms that marking visibility is not merely a physical attribute of road infrastructure, but also a perceptual factor that directly affects how drivers interpret and respond to traffic control elements. Even though the magnitude of the coefficient is moderate (Beta = 0.142), its statistical significance highlights that improving the clarity of markings can meaningfully influence driver decision-making when approaching intersections.

The positive direction of the coefficient suggests that the relationship between perceived clarity and violation behavior is influenced by subjective interpretation, where drivers who perceive markings as clearer may also be those who are more aware of their position relative to the stop line, including instances where they recognize themselves as having violated it. This indicates that perception does not always translate linearly into compliance, but instead reflects a more complex behavioral response involving awareness, experience, and interpretation of road conditions.

Furthermore, when compared to other variables in the model, perceived marking clarity remains significant alongside ETLE awareness (B = -0.475; p = 0.000) and improved marking perception (B = -0.384; p = 0.000), both of which show stronger effects in reducing violations. This suggests that while enforcement and actual improvements in marking conditions have a more dominant influence, perceived clarity still plays a critical supporting role in shaping compliance behavior.

Overall, the findings highlight that enhancing the clarity of stop line markings is an important intervention, not only from a physical infrastructure perspective but also from a perceptual standpoint. Improving how drivers visually perceive road markings can contribute to better compliance, particularly when combined with strong enforcement measures and improved marking conditions.

5. Conclusion

This study demonstrates that the clarity of stop line markings has a significant influence on road user compliance at urban intersections. The Difference-in-Differences (DiD) analysis shows that the violation rate at the intersection with clear markings is 22.0%, while at the intersection with faded markings reaches 37.7%, resulting in a difference of 15.6%. This finding indicates that clearer markings are associated with a substantial reduction in violation behavior. In addition, the speed profile analysis reveals that vehicles at the intersection with faded markings maintain higher speeds at all observed distances, with the largest difference occurring at 20 meters, where the speed gap reaches 4.74 km/h. This suggests that faded markings lead to delayed deceleration, while clear markings encourage earlier and more gradual speed reduction.

Furthermore, the multiple linear regression results show that perceived marking clarity has a statistically significant effect on violation behavior, with a coefficient (B = 0.112) and a significance value of 0.029. Although the direction of the relationship is positive, this finding reflects that driver perception of marking clarity is closely related to their awareness and interpretation of stopping behavior, rather than directly indicating increased compliance. The model explains 50.4% of the variation in violation behavior ($R^2 = 0.504$), indicating a moderate to strong explanatory power. Among all variables, ETLE awareness shows the strongest influence (B = -0.475; p = 0.000), followed by improved marking perception (B = -0.384; p = 0.000). Meanwhile, other variables such as driving behavior, law enforcement perception, and demographic factors are not statistically significant. Overall, these results suggest that while enforcement and actual improvements in marking conditions play a dominant role, perceived clarity remains an important supporting factor in shaping driver behavior at urban intersections.

Theoretically, these findings contribute to the understanding of infrastructure-behavior interaction in traffic engineering, reinforcing that road markings serve as active behavioral cues that mediate driver decision-making, not merely passive physical boundaries. The results also extend the literature on enforcement-infrastructure complementarity, showing that ETLE effectiveness is contingent on adequate marking quality. For urban road safety management, these positions stop line marking maintenance as a strategic safety investment rather than a routine operational task, with implications for how enforcement and infrastructure policies should be designed and integrated in rapidly urbanizing cities.

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