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Original Article

Traffic Management Analysis and Mitigation of Counter-Flow Violations Using Traffic Conflict Techniques in Alam Sutera, Tangerang

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Abstract

Wrong-Way Driving (WWD) by motorcycle riders is a critical safety issue in urban Indonesia, with the Alam Sutera area, Tangerang, recording 1,126 violators in a single peak-hour observation. This study formulates an integrated traffic management and mitigation strategy for the phenomenon of Wrong-Way Driving (WWD) in the Alam Sutera area. The primary issue is driven by the inefficiency of the legal route (1,800 m) compared to the WWD route (270.1 m), which creates a justification for speculative behavior. Proactive safety analysis using the Swedish Traffic Conflict Technique (TCT) identified an extreme fatality risk with an average Time-to-Accident (TA) value of 0.7 seconds, with 80% of interactions categorized as serious conflicts. Questionnaire analysis based on the Theory of Planned Behavior (TPB) confirmed a critical detour distance threshold at >1,000 m, which serves as a trigger point for driving violations. Evaluation through VISSIM microsimulation (validated with GEH value < 5 and MAPE value < 50%) shows that Scenario 3 is the most optimal mitigation. By implementing a 1.20 km alternative route via the roundabout, installing permanent physical barriers, and optimizing the traffic signal cycle time from 143 seconds to 90 seconds, the traffic volume load at the conflict point was significantly redistributed. This strategy effectively enhancing operational performance by reducing average delay to 20.34 seconds/vehicle at Level of Service (LOS) C.

Keywords: Theory of Planned Behavior, Traffic Conflict Technique (TCT), Traffic Management, VISSIM, Wrong-Way Driving.

1. Introduction

Transportation in Indonesia has developed rapidly over the past two decades, marked by a surge in the number of private vehicles, particularly motorcycles. Two-wheeled vehicles have become the primary choice for the public due to their affordable prices, ease of maneuvering, and efficiency for short to medium distances. However, this growth has not been matched by adequate road infrastructure development, either in terms of capacity or traffic management systems. This disparity has given rise to various violations, one of which is wrong-way driving (WWD) behavior, which poses a high risk to road safety.

The Alam Sutera area, Tangerang City, has become one of the critical points of this phenomenon. On the road segment of Jalur Sutera Street toward Gempol Raya Street, motorcycle riders frequently choose an illegal shortcut of approximately ±200 meters to avoid a U-turn distance of approximately ±1.8 km. Based on surveys conducted during peak periods (rush hour), the number of violators was recorded at 1,126 riders in a single observation session. This phenomenon is exacerbated by the high mobility of Tangerang City residents, which reached 1.965 million people in 2024 (BPS, 2024).

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To comprehensively analyze and mitigate WWD, this study integrates two complementary frameworks. The Theory of Planned Behavior (TPB) (Ajzen, 1991) explains WWD as a deliberate act shaped by individual attitudes, subjective norms, and perceived behavioral control, with detour distance tolerance as a key trigger. The Swedish Traffic Conflict Technique (TCT) (Hydén & Linderholm, 1984) provides a proactive safety measure using Time-to-Accident (TA) and Conflicting Speed (CS) to identify near-miss risks without relying on historical accident data. These frameworks are complementary because TPB identifies why riders choose to violate (psychological drivers), while TCT quantifies the resulting safety consequences (conflict severity). Together, they enable an integrated traffic management strategy that addresses both behavioral intentions and physical risk exposure.

Addressing this phenomenon does not rely solely on accident data that has already occurred. Given the potential for underreporting in the IRSMS system, a proactive approach through the identification of near-miss incidents is critically important to prevent more fatal risks in the future. Based on safety risk data in the jurisdiction of Polres Metro Tangerang Kota for the period 2016-2025, wrong-way driving violations are the primary trigger factor for fatal accidents in the Tangerang City area. This is reflected in 197 cases of head-on collisions resulting in 35 fatalities and 84 serious injuries, consistent with the risk of frontal impact caused by WWD. The high number of rear-end collisions (790 cases) and side collisions (626 cases) also indicate secondary risks (induced risks), where illegal traffic flow forces legal road users to brake suddenly or change lanes abruptly, triggering chain collisions. This phenomenon is compounded by infrastructure design that encourages the intent to violate for the sake of illusory time efficiency (Polda Metro Jaya, 2025).

In academic studies, WWD research has examined user psychological factors (Satiennam et al., 2023), the influence of road design (Song et al., 2024), and the effectiveness of monitoring policies (Ponnaluri, 2016). These studies indicate that WWD is the result of an interaction between technical and behavioral factors. However, most research still discusses both aspects separately and has not yet utilized microscopic simulation as an instrument for developing infrastructure alternatives in the context of urban Indonesia.

The primary need that emerges is a traffic management approach that is not merely theoretical, but also presents applicable mitigation strategies that account for the risk compensation tendencies of riders. The identified gap is the limited number of studies that integrate proactive safety analysis based on the Swedish Traffic Conflict Technique (TCT) method with analysis of distance tolerance thresholds as a basis for infrastructure design.

The PTV VISSIM microsimulation approach provides a quantitative overview of traffic performance, particularly in testing cycle time reduction scenarios as incentives for users of legal routes. This research is directed at formulating integrated traffic management that combines geometric engineering and operational optimization, analyzing WWD patterns at Severity Level 30, and designing physical interventions in the form of road barrier extensions in accordance with the psychological thresholds of riders. The expected outcome is a rational technical recommendation toward a Zero WWD target for a safer and more efficient traffic system in urban Indonesia.

Based on the background that has been described, the problem formulation in this research encompasses three main aspects. First, how do psychological factors comprising Attitude, Subjective Norm, and Perceived Behavioral Control, as well as perception of detour distance (detour acceptance), influence the intention of motorcycle riders to commit wrong-way driving violations in the Alam Sutera area. Second, how is the level of proactive road safety risk at the study location if measured through the identification of near-miss incidents using the parameters of Time-to-Accident (TA) and Conflicting Speed (CS) under existing

conditions. Third, how does the visualization of WWD mitigation scenario modeling results evaluate geometric arrangement and traffic access management in the Alam Sutera area.

This research aims to analyze the psychological factors and technical factors in the form of detour distance perception that constitute the main determinants of the intention to commit wrong-way driving violations by motorcycle riders at the study location. In addition, this research also aims to evaluate the level of road safety risk proactively and traffic performance at the violation location by identifying near-miss incidents using the Swedish TCT method. Finally, this research evaluates the geometric arrangement design and access management in WWD mitigation scenarios through VISSIM microsimulation visualization to ensure the creation of orderly and smooth traffic circulation in the Alam Sutera area.

Theoretically, this research enriches transportation science through the integration of the Theory of Planned Behavior and Surrogate Safety Measures, while also offering a road safety evaluation methodology that does not depend on historical accident data that is prone to underreporting. Practically, the research results can be utilized directly by area managers, the Department of Transportation, and the Traffic Police to formulate infrastructure improvement strategies. The technical recommendations produced (covering route changes, addition of median separators, realignment of U-turn points, and installation of signs) are empirical, measurable, and replicable in similar situations. Socially, this research is expected to improve road safety standards for road users in the Alam Sutera area, while also encouraging the formation of a culture of orderly traffic behavior through the reduction of conflict points caused by wrong-way driving.

This research is structured to address the problem of traffic violations in the form of wrong-way driving (WWD) by motorcycle riders in the Alam Sutera area, Tangerang. Given the complexity of traffic problems, a number of limitations are established so that the scope of the study is more focused and methodologically consistent. In terms of location, the research is focused on the area of Jalur Sutera Street toward Gempol Raya Street, Alam Sutera, Tangerang City, which was selected based on the highest frequency of violations from initial observations. The primary object of the research is motorcycle riders who commit wrong-way driving violations, while four-wheeled or larger vehicles are not analyzed in depth because motorcycles are the dominant perpetrators of WWD at the study location.

In terms of the type of violation, the study is limited only to wrong-way driving violations. Other violations such as helmet use or vehicle administrative completeness are outside the scope of analysis. The solution approach is also focused on technical aspects of infrastructure engineering and traffic management, where the analysis of road user behavior based on the Theory of Planned Behavior is used as input parameters in microscopic simulation, not as a purely psychological study. Finally, the evaluation of mitigation solution designs is carried out entirely through VISSIM microsimulation. This research does not cover the analysis of criminal legal regulatory aspects or the direct implementation of social campaigns.

2. Literature Review

2.1. Transportation and Road Infrastructure

Transportation is the activity of moving people and goods from one place to another that depends on three main components: means, infrastructure, and an operational system that manages the flow of movement (Morlok, 1978). In an urban context, transportation plays a vital role in supporting community activities and regional growth. The efficiency of a transportation system is closely related to accessibility, mobility, and environmental

sustainability, characterized by an integrated network, efficient travel time, and minimal external impacts such as pollution and accidents (Litman, 2022).

Infrastructure as a physical system supporting transportation encompasses roads, drainage, buildings, and other public facilities needed to support the basic social and economic needs of society (Grigg, 1988). The quality of infrastructure design greatly influences safety, efficiency, and riding comfort (AASHTO, 2018). Roads as the main component are understood as land transportation infrastructure that functions to channel traffic flow, based on Law Number 2 of 2022 on Roads. Roads must be designed to naturally direct user behavior through geometric design, adequate signage, markings, and lane dividers (AASHTO, 2018).

2.2. Traffic Characteristics and Performance

Traffic characteristics represent the interrelationship between drivers, vehicles, and road conditions, encompassing three main parameters: flow, speed, and density (Januardi et al., 2018). Density describes the number of vehicles per unit length of road, flow is expressed as the number of vehicles passing a point per unit of time, and speed is defined as the average value of distance traveled per unit of time for all vehicles in the flow (PKJI, 2023).

Traffic performance is assessed through the Level of Service (LOS), a qualitative indicator reflecting the level of ease, comfort, and smoothness of vehicle movement (HCM, 1994). From a geometric perspective, road design determines operational speed and overall driving safety outcomes (Roess & Prassas, 2011). Intersections as critical elements of the road network are defined as parts of the road connecting two or more road segments and allowing vehicles to change direction (KEMENHUB RI, 2015). At signalized intersections, the use of traffic signals is intended to optimize intersection capacity during the busiest hours while reducing the potential for collisions between vehicles from opposing directions (PKJI, 2023).

2.3. Proactive Traffic Safety

Road safety is defined as the condition that ensures every road user is free from the risk of accidents in the utilization of road traffic (Regulation of the Minister of Transportation of the Republic of Indonesia Number 96 of 2015). Traditionally, safety is measured through historical accident data of a reactive nature. However, data limitations due to underreporting have driven the use of a proactive approach through Surrogate Safety Measures (SSM), which allows for risk identification without having to wait for accidents to occur (Hosseini et al., 2021).

Several main SSM indicators commonly used include Time-to-Collision (TTC), Post-Encroachment Time (PET), Deceleration Rate to Avoid Collision (DRAC), and Time-to-Accident (TA). The weakness of using a single indicator such as TTC or PET is its inability to integrate the speed variable (Conflicting Speed/CS) as a determinant of collision severity, particularly in WWD cases involving sudden trajectory changes (Hydén & Linderholm, 1984).

2.4. Wrong-Way Driving and Behavioral Factors

Wrong-way driving (WWD) is driving behavior that does not conform to the prescribed direction on a road segment, generally performed to avoid a long U-turn distance (Amir et al., 2024). This violation is extremely dangerous because it has the potential to cause head-on accidents and conflicts from the opposite direction. Its driving factors include inefficient road design, lack of lane dividers, weak enforcement, and psychological factors such as social norms and risk perception. A study by Satiennam et al. (2023) shows that subjective norms and behavioral control greatly influence riders' intention to violate traffic flow, while Sirait and Santoso (2024) add that moral obligation and perception of surveillance are more dominant in shaping riding behavior.

2.5. Traffic Simulation (VISSIM)

PTV VISSIM is a microscopic simulation software that depicts interactions between individual vehicles and is used to assess traffic system performance based on road design and signal settings. VISSIM's advantage lies in its ability to realistically visualize the impact of infrastructure changes, including the effect of interventions such as the addition of separators or changes to U-turn lanes. Validation of simulation results is performed using GEH statistics with a target score below 5 and multi-run procedures to accommodate stochastic variations in vehicle behavior (PTV Group, 2020). In the context of this research, VISSIM is used to compare scenarios before and after WWD mitigation interventions as a basis for technical recommendations to policy makers (Song et al., 2024).

3. Methods

3.1. Research Design

This research uses an explanatory quantitative approach with three integrated stages. First, behavioral data are collected from 95 WWD violators using a TPB-based questionnaire to measure perceived behavioral control, detour distance tolerance, and mitigation acceptance, analyzed via validity (Pearson), reliability (Cronbach's Alpha), regression, and T-test. Second, proactive safety analysis applies the Swedish TCT to 100 near-miss incidents (50 on WWD lane, 50 at merging) using TA and CS parameters to classify serious vs. non-serious conflicts against Lund University Level 26 threshold. Third, PTV VISSIM microsimulation models base and three mitigation scenarios (signal optimization; signal+barrier; signal+barrier+new 1.20 km roundabout route), validated with GEH<5 and MAPE<50%, evaluating average delay (sec/veh) and LOS.

3.2. Population and Sample

The research population encompasses 1,126 motorcycle riders who committed wrong-way driving violations on Jalan Jalur Sutera based on observation results. The sample was determined using a purposive sampling technique with the criterion of riders who have committed violations. The sample size was calculated using the Slovin formula ($\alpha = 0.1$) and 95 respondents were obtained. Respondent data was used to form behavioral distributions in the PTV VISSIM simulation to represent route selection tendencies and mitigation scenario evaluation.

3.3. Research Instruments

Research instruments include a questionnaire to measure the psychological aspects of riders based on the Theory of Planned Behavior (TPB) and detour distance tolerance, as well as video observation to obtain data on volume, vehicle classification, and traffic conflicts as modeling inputs. In addition, PTV VISSIM microscopic simulation was used to test mitigation scenarios with performance indicators such as V/C ratio and delay, validated using GEH statistics (<5) and MAPE. Conflict severity analysis was performed using the Swedish TCT method through the parameters of Time-to-Accident (TA) and Conflicting Speed (CS) to identify the level of safety risk.

3.4. Data Collection Techniques

Data collection techniques in this research were designed to obtain objective numerical data as the primary input in microsimulation modeling and statistical analysis. Data collection was carried out through several methods, namely traffic volume and characteristics surveys using video counting on the Jalan Jalur Sutera segment and the signalized intersection to

obtain data on vehicle volume, vehicle type classification, and violation frequency during peak hours (16:00-18:00 local time) and off-peak hours. In addition, a rider behavior survey was conducted using a structured questionnaire based on a Likert scale (1-5) with 95 respondents to measure the Theory of Planned Behavior (TPB) variables and detour distance tolerance (detour acceptance). Data was also supplemented through documentation studies and secondary data in the form of road geometric drawings (as-built drawings) and historical accident data from the IRSMS of Polres Metro Tangerang Kota for the period 2016-2025 as a basis for safety risk validation. Subsequently, conflict data extraction was performed through simulation using PTV VISSIM software to model existing conditions and proposed improvement scenarios.

3.5. Research Procedures

The research procedure begins with data collection through geometric surveys, video counting for volume, speed, and violations, as well as secondary IRSMS accident data. Subsequently, a questionnaire survey was conducted with 95 respondents to measure Theory of Planned Behavior (TPB) variables and distance tolerance, which were used as behavioral inputs in the simulation. The next stage was the construction and calibration of the existing model using PTV VISSIM with GEH validation (<5). Mitigation scenarios were then developed comprising signal optimization, access arrangement, and geometric engineering. The final stage involved traffic performance evaluation (V/C ratio and delay) to determine the best recommendation.

3.6. Data Analysis Stages

The data analysis stages were carried out in an integrated manner encompassing behavioral, traffic performance, and safety analysis. Behavioral analysis used the Theory of Planned Behavior (TPB) approach through validity testing (Pearson), reliability testing (Cronbach's Alpha), multiple linear regression, and T-test to identify the influence of psychological factors on the intention to violate. Subsequently, traffic performance analysis referenced PKJI 2023 through the calculation of capacity (C) and degree of saturation (Dj = q/C). Safety analysis was performed using the Swedish TCT method with the Time-to-Accident (TA) parameter to identify conflict levels. The VISSIM microsimulation model was validated using GEH statistics and MAPE to ensure result accuracy as a basis for mitigation scenario evaluation.

4. Results and Discussion

4.1. Analysis of Rider Behavior Toward WWD Violations

This behavioral analysis aims to dissect the psychological aspects and environmental controls that influence the intention of motorcycle riders to commit wrong-way driving violations.

4.1.1. Validity and Reliability Testing of Instruments (Q12 - Q19)

Validity testing was performed to ensure that each statement item (Q12-Q19) truly represents the research variable, while reliability testing measures the level of consistency in respondent answers.

Table 1. Validity Test Results for Statement Items (N=30)

Code	Statement Dimension	R-Value	R-Table (5%)	Status
Q12	Night/Quiet Condition Factor (PBC)	0.742	0.361	Valid
Q13	Lack of Officer Supervision Factor (PBC)	0.689	0.361	Valid
Q14	Detour Distance Too Far Factor (PBC)	0.812	0.361	Valid
Q15	Absence of Physical Barrier (PBC)	0.655	0.361	Valid
Q16	Acceptance of U-Turn Relocation (Mitigation)	0.718	0.361	Valid
Q17	Acceptance of Traffic Signal Optimization (Mitigation)	0.798	0.361	Valid
Q18	Acceptance of WWD Lane Closure (Mitigation)	0.692	0.361	Valid
Q19	Acceptance of Tidal Flow System (Mitigation)	0.704	0.361	Valid

Source: SPSS Data Processing Results, 2026

Table 2. Reliability Test Results by Variable

Research Variable	Cronbach's Alpha	Critical Value	Status
Perceived Behavioral Control (Q12-Q15)	0.724	0.600	Reliable
Selected Mitigation Strategies (Q16-Q19)	0.781	0.600	Reliable

Source: SPSS Data Processing Results, 2026

The test results in Table 1 show that all statement items (Q12 through Q19) have R-value that far exceed the R-table (0.361), with the highest value achieved by Q14 (0.812). This indicates that the questionnaire instrument is highly accurate in capturing riders' perceptions of the detour distance obstacle as a driver of violating behavior. In terms of reliability, Table 2 shows Cronbach's Alpha values above 0.7, meaning respondents provided consistent answers to those statement items. The strength of this instrument provides assurance that the processed data has high scientific validity for use as a basis for designing behavior-based mitigation scenarios in the VISSIM simulation.

4.2. Descriptive Analysis of Respondent Characteristics and Perceptions

The profile of wrong-way driving (WWD) perpetrators in the Alam Sutera area is dominated by the productive age group, namely Late Adolescents (17-25 years) at 33.7% and Late Adults (36-45 years) at 28.4%. In terms of occupation, the majority of respondents have a high level of daily mobility, consisting of the Entrepreneur group (29.5%) and Online Motorcycle Taxi Drivers and Couriers (27.4%), of whom 35.8% pass through the study location more than 8 times per day. This characteristic of intense mobility indicates that violating behavior is not merely an incidental act, but rather a habituation that reinforces Perceived Behavioral Control because riders feel they have mastered the risks of the road (Sirait & Santoso, 2024). Analysis of violation intention shows a very high level of risky behavior, with 57.9% of respondents stating they "Often" to "Always" commit WWD for time savings of more than 15 minutes (50.5%). Psychologically, WWD is regarded as a "pragmatic" solution to avoid the inefficiency of the legal route, which is currently perceived to far exceed the rational limits of their travel time (Ajzen, 1991).

The most crucial finding in this perception analysis is the high tolerance threshold of respondents toward detour distance. Cumulatively, the majority of respondents at 68.4% (combined category of 1,000 meters at 36.8% and >1,000 meters at 31.6%) have the psychological readiness to accept detour routes of considerable distance. This fact provides a strong sociological foundation for the planned implementation of a new road, even though such a route would add to the travel distance. Acceptance of the >1,000 meter distance threshold is supported by road users' desire for certainty of smooth travel time; 57.9% of

respondents stated their willingness to stop violating if the official route is guaranteed to take a reasonable travel time (<5 minutes).

The bar chart of PBC frequency shows that the Detour Distance Too Far Factor (Q14) and Lack of Officers Factor (Q13) are the most dominant behavioral control variables influencing respondents' intention to commit WWD. A total of 76 respondents stated that the inefficient U-turn route was their main reason for feeling they had control to violate, reflecting a rational choice phenomenon in which the operational cost of taking the legal route is considered too high (Sirait & Santoso, 2024). Meanwhile, the high frequency on variable Q13 (75 respondents) indicates that weak physical supervision reduces the perceived risk of apprehension, thereby further strengthening individual behavioral control to violate. Conversely, the Night Factor (Q12) with its even distribution shows that violations are committed consciously under various time conditions, as long as the distance (geometry) and supervision variables remain gaps for riders (Ajzen, 1991).

Interpretation of several mitigation scenarios through histogram charts shows a very strong public consensus on APILL Optimization (Q17), with 68.4% of respondents stating "Strongly Agree." This indicates that long red light durations represent the primary psychological burden that triggers the desire to violate. The distribution for U-Turn Relocation (Q16) and WWD Stop Criteria (Q18) concentrated in the "Agree" category provides a technical mandate that respondents support physical changes provided they are accompanied by travel time efficiency. By providing infrastructure that is smooth and meets the community's distance tolerance threshold (1,000m - >1,000m), individual behavioral control to violate will be systematically reduced, transforming patterns of illegal movement into compliance with safer and more sustainable official routes in the Alam Sutera area (Zhang et al., 2024).

4.3. Regression Analysis of the Influence of PBC Factors on WWD Frequency

Regression testing was performed to determine which behavioral control variables most significantly trigger riders' decisions to violate.

Table 3. Regression Coefficients of PBC Variables on WWD Behavior

Independent Variable	Coefficient B	t-value	Significance (Sig.)	Remarks
(Constant)	3.967	6.224	0.000	
Q12 (Night Condition)	0.438	3.665	0.000	Significant
Q13 (Lack of Officers)	0.305	1.514	0.134	Not Significant
Q14 (Detour Distance Too Far)	-0.679	-3.379	0.001	Significant
Q15 (Absence of Barrier)	-0.100	-0.658	0.512	Not Significant
F-Test (Simultaneous)	F = 5.443		0.001	Significant

The linear regression analysis in Table 3 reveals that perception of detour distance (Q14) is the primary determining factor influencing the frequency of wrong-way driving violations. The negative coefficient of -0.679 with a significance value of 0.001 reflects that the greater the psychological burden of riders toward the far official route (1,800 m), the more their behavioral control to comply with traffic regulations will weaken (Ajzen, 1991). This condition creates a rational choice phenomenon at the study location, where riders consciously evaluate that the operational cost and time required to take the legal route is no longer rational compared to the risk of violating on the illegal route of 270.1 m (Sirait & Santoso, 2024).

The fact that the variables of lack of supervisory officers (Q13) and absence of physical barriers (Q15) do not have a significant influence in this model provides a crucial finding that the motivation to violate in the Alam Sutera area is more driven by the desire to pursue route efficiency rather than merely exploiting weaknesses in field supervision. This is reinforced by the significant influence of nighttime conditions or when traffic is sparse (Q12), which provides a "false sense of security" for violators to maneuver. Therefore, interventions that rely solely on manual supervision will not be sustainably effective because they do not resolve the root cause, which is the inefficiency of road geometry.

4.4. One-Sample T-Test on Mitigation Strategies (Q16 - Q19)

This test aims to evaluate the level of respondent agreement toward the engineering solutions to be tested in the VISSIM simulation.

Table 4. One-Sample T-Test Results for Mitigation Acceptance Levels

Mitigation Variable	Mean	t-value	Sig. (2-tailed)	Conclusion
Q16 (U-Turn Relocation)	3.79	8.144	0.000	Agree
Q17 (Traffic Signal Optimization)	4.34	11.885	0.000	Strongly Agree
Q18 (Barrier Installation)	3.66	6.784	0.000	Agree
Q19 (Tidal Flow System)	3.58	5.922	0.000	Agree

Test Value = 3.00 (Neutral)

The level of public acceptance toward the several mitigation strategies tested through the One-Sample T-Test in Table 4 shows very strong sociological support, where all variables obtained a significance score of 0.000 exceeding the neutral test value (3.00). Traffic signal optimization (Q17) recorded the highest score of 4.34, which proves that road users collectively consider the failure of time management at the main intersection to be the primary driving factor of violating behavior. Significant support for U-turn relocation (Q16) with an average of 3.79 confirms riders' readiness to switch to the legal route, provided the route is able to offer efficiency that is more competitive than existing conditions. This finding implies that the plan to redirect traffic to a longer but smooth route is a solution with high public acceptance. The success of this mitigation is closely related to travel time certainty, where 57.9% of respondents expressed willingness to stop WWD behavior if the official route is guaranteed to have smooth operational travel time (Sirait & Santoso, 2024).

4.5. Proactive Safety Analysis with Traffic Conflict Technique (TCT)

Proactive safety analysis was conducted to evaluate the level of accident risk at the study location scientifically without having to wait for real crash data to occur.

4.5.1. Matrix for Determining Time-to-Accident (TA) Values

This matrix serves as a theoretical reference for understanding how the interaction between operational speed and gap distance produces the available reaction time (TA) before a potential collision occurs. TA values in Tables 5 and 6 are calculated as TA = d / V, where d = gap distance (m) and V = subject rider's speed (m/s). This formula assumes constant speed and no deceleration, providing an upper-bound estimate for a single road user (the violator or merging rider). Limitations include the exclusion of reaction time lag, deceleration capability, and relative closing speed in head-on scenarios (which would further reduce TA). Despite these simplifications, the Swedish TCT framework accepts TA = d/V for conflict screening when thresholds (e.g., Level 26) are interpreted conservatively.

Table 5. TA Value Matrix for Area 2 (WWD / Illegal Lane)

Speed (km/h)	Speed (m/s)	1.0m	2.0m	4.0m	6.0m	8.0m	10.0m
15	4.17	0.24	0.48	0.96	1.44	1.92	2.40
20	5.56	0.18	0.36	0.72	1.08	1.44	1.80
25	6.94	0.14	0.29	0.58	0.86	1.15	1.44
30	8.33	0.12	0.24	0.48	0.72	0.96	1.20

This matrix shows critical conditions on the WWD lane. With the limited lane width, the majority of interactions occur at gap distances below 10 meters. At an operational speed of 25 km/h with a gap distance of 4 meters, the TA value of 0.58 seconds is far below the serious threshold (Level 26). This indicates that wrong-way maneuvering fundamentally does not provide sufficient safety margin for riders.

Table 6. TA Value Matrix for Area 3 (Point B / Merging)

Speed (km/h)	Speed (m/s)	10m	15m	20m	30m	40m	50m
35	9.72	1.03	1.54	2.06	3.09	4.11	5.14
40	11.11	0.90	1.35	1.80	2.70	3.60	4.50
45	12.50	0.80	1.20	1.60	2.40	3.20	4.00
50	13.89	0.72	1.08	1.44	2.16	2.88	3.60

On the official route (merging), the matrix shows a more distributed risk profile due to longer sight distances and gap distances (d ≥ 10m). However, the high speed of the main traffic flow (V ≥ 40 km/h) causes TA values to still be able to reach critical areas even though the physical distance appears far.

4.6. Recapitulation of Conflict Observation Results

The following table summarizes data from 100 observations of near-miss incidents conducted during peak hours.

Table 7. Statistical Summary of Traffic Conflict Observation Results

Parameter	Area 2 (WWD Lane)	Area 3 (Merging Point)
Sample Size (n)	50 Incidents	50 Incidents
Average Speed (V)	18.5 km/h	42.3 km/h
Average Reaction Distance (d)	3.8 meters	12.4 meters
Average TA Value	0.7 seconds	1.1 seconds
SERIOUS Conflict Frequency	40 Incidents (80%)	34 Incidents (68%)
NON-SERIOUS Conflict Frequency	10 Incidents (20%)	16 Incidents (32%)

The recapitulation data shows that the WWD lane has a very persistent level of danger with 80% of incidents categorized as serious. Although the average speed on the WWD lane is low (18.5 km/h), the very narrow inter-vehicle gap distances cause TA values to frequently be below 0.5 seconds. Conversely, in the merging area, although the reaction distance is more spacious, the high vehicle speed causes 68% of conflicts to still fall into the serious category, because the available avoidance time is not proportional to the kinetic energy of vehicles at high speed.

4.7. Interpretation of Conflict Boundary Charts (Swedish TCT)

The conflict boundary chart visualizes the position of 100 conflict incidents from observation results onto the standard severity curve of Lund University. The Red Line (Level 26) is the critical threshold separating normal interactions from serious conflicts.

4.7.1. Analysis of the WWD Lane Cluster (Area 2)

The majority of WWD observation points (80%) are located on the lower left side of the chart, clustered between the Level 26 and Level 30 lines. These points show that every wrong-way driving action at the study location consistently produces a life-threatening safety hazard, as the small TA values (average 0.7 seconds) prove the absence of a tolerance margin for riders to perform avoidance maneuvers in the event of an anticipation failure. The remaining 20% of data located above the curve occurred when the volume of oncoming vehicles was very low, giving riders a sufficiently wide gap distance (d > 8m).

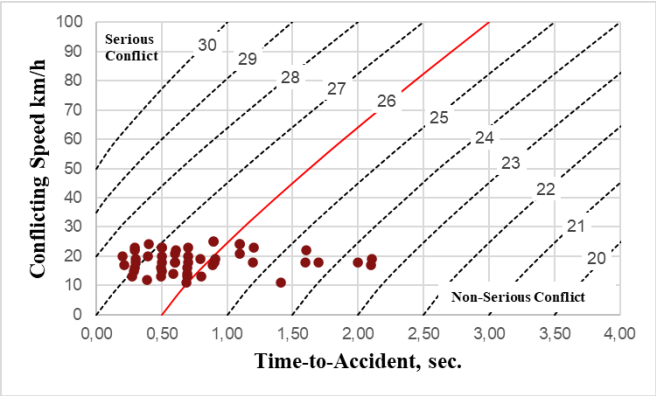


Figure 1. Serious Conflict Chart for the WWD Area



Figure 2. Conflict Type Chart for the WWD Area

4.7.2. Analysis of the Official Route / Merging Cluster (Area 3)

The coordinate points in the merging area show a pattern that is more spread out following the “fan” direction of the curve. A total of 68% of incidents are in the serious zone, indicating that risk in the merging area is highly sensitive to operational speed. Even though the movement is legal, the high speed of vehicles from the main flow means that the meeting of traffic flows still carries a moderate fatality risk. Unlike the WWD risk which is fundamental in nature (wrong direction), the risk on the official route is operational and can be mitigated through intersection speed management or improvement of merging markings.

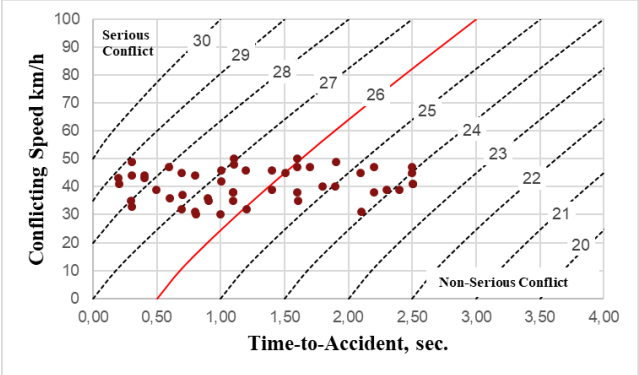


Figure 3. Serious Conflict Chart for the Merging Area



Figure 4. Conflict Type Chart for the Merging Area

The high frequency of serious conflicts on the WWD lane (80%) proves the existence of an extreme safety margin failure caused by illegal movement. From the perspective of the Swedish Traffic Conflict Technique, a serious conflict occurs when the time available for a rider to avoid (TA) is below the critical threshold at a given speed (Hyden, 1987). The phenomenon in Area 2 (WWD) shows that even though the violator's speed is relatively low (18.5 km/h), the very narrow inter-vehicle gap distances (d < 4 m) create conditions in which a collision is almost unavoidable without emergency evasive action. This is consistent with the research of Sirait & Santoso (2024), which states that wrong-way conflicts have greater potential kinetic energy damage because the collision direction tends to be frontal (head-on), thereby significantly increasing injury severity.

Conversely, the conflict characteristics in Area 3 (Merging) show that risk is more influenced by the operational speed factor of the main flow than by maneuvering errors. Although 68% of data falls into the serious category, the position of points on the chart is generally near the threshold line (Level 26), not in the inner zone as on the WWD lane. This indicates that risk on the official route is operational in nature and can be mitigated through intersection geometric engineering or speed limit regulation (Swedish TCT Manual, 2018).

The integration of these TCT results provides absolute technical justification for the selection of Scenario 3 (New Road of 1.20 km) as the primary mitigation solution. Based on the results of the TPB questionnaire (Appendix 4), the majority of respondents have a detour distance tolerance threshold of 1,000 meters. Although the construction of a new road adds a detour distance to 1.20 km (slightly above the ideal threshold), this step is fundamentally capable of eliminating 80% of serious conflict risks that currently occur on the WWD lane. In transportation safety management, diverting traffic to a longer but orderly route (orderly flow) is far more effective than maintaining a short route with a high fatality probability (Laureshyn et al., 2017). Accordingly, providing new road infrastructure of 1.20 km represents a rational

safety trade-off for road users to avoid the saturation point and fatal risks in the Alam Sutera area.

4.8. Evaluation of Mitigation Scenarios through VISSIM Microsimulation

Scenario evaluation was conducted to visually review how the proposed geometric improvement and access management proposals are able to accommodate vehicle circulation. VISSIM was used to prove that the offered design is capable of creating orderly flow without disrupting overall system performance.

4.8.1. Base Model Validation

Validation is a crucial stage to ensure the simulation model has represented real field conditions with a scientifically accountable level of accuracy. The model fit level is measured using GEH (Geoffrey E. Havers) statistics, which compares simulation volume results (Qsim) with field observation volume (Qobs).

Table 8. VISSIM Model Vehicle Volume Validation Results

Intersection Arm	Qobs (veh/hr)	Qsim (veh/hr)	GEH Value	MAPE (average)	Status
South Arm	2,073	2,150	0.19	6.70%	Valid
North Arm	927	966	0.20		
East Arm	873	1,050	0.42		
West Arm	1,527	1,650	0.27		
Merging	2,500	2,504	0.31	19.22%	Valid
Sushi Intersection	400	550	0.87		
WWD	85	90	0.77		
Gempol	600	800	1.35		

Source: Microsimulation Data Processing Results (2026)

The data processing results in Table 8 show GEH statistical values in the range of 0.19 to 1.35 and MAPE statistical values (average) of 6.70 and 9.22. These values are far below the tolerance threshold (GEH < 5) and (MAPE < 50%), which proves that the simulation model has a high level of accuracy and is scientifically valid for use as a basis for engineering decision-making. With this valid status, the simulation model can be relied upon to analyze the impact of operational and structural mitigation scenarios.

4.8.2.Scenario 1: Traffic Signal Cycle Time Optimization (90-Second Cycle)

Scenario 1 focuses on reducing waiting time at the main intersection to break up long queue accumulation at the South Arm.

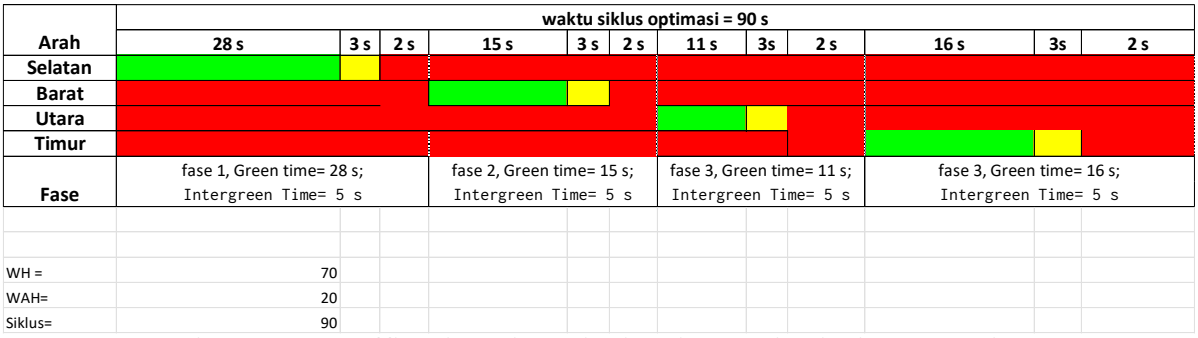


Figure 5. Traffic Signal Optimization Calculation Results

Table 9. Comparison of Traffic Signal Timing Settings

Parameter	Existing Condition	Scenario 1 (Optimization)	Change
Cycle Time (c)	143 Seconds	90 Seconds	-53 Seconds
Phase 1 (South Arm)	38 seconds	22 seconds	-16 seconds
Phase 2 (North Arm)	28 seconds	15 seconds	-13 seconds
Phase 3 (East Arm)	17 seconds	10 seconds	-7 seconds
Phase 4 (West Arm)	16 seconds	9 seconds	-7 seconds
Lost Time	44 seconds	34 seconds	-10 seconds

Source: Traffic Signal Optimization Analysis Results (2026)

The change in cycle time from 143 seconds to 90 seconds significantly improves phase change efficiency. The reduction in lost time by 10 seconds allows vehicles to have more frequent passage opportunities per hour, which effectively prevents the accumulation of motorized vehicles that typically triggers psychological saturation for commuter riders.

Table 10. Comparison of Operational Performance for Scenario 1

Performance Parameter	Existing Condition (Base)	Scenario 1 (Signal Optimization)	Effectiveness (%)
Average Delay (sec/veh)	22.63	17.5	7.20%
Level of Service (LOS)	C	C	Stable

Source: Microsimulation Analysis Results (2026)

The implementation of Scenario 1 through cycle time reduction has been technically proven to reduce the average delay value by 7.41%. However, this signal timing optimization has not addressed the root geometric problem, so the gap for riders to commit wrong-way driving (WWD) violations remains open and the potential for crossing conflicts that result in fatalities still poses a threat.

4.8.3.Scenario 2: Signal Optimization and Tactical Barrier (115.42 m Barrier)

Scenario 2 is a short-term intervention strategy that combines signal optimization with physical closure of illegal access using a barrier of 115.42 meters in length.



Figure 6. Solution 2 Design

Table 11. Comparison of Operational Performance for Scenario 2

Performance Parameter	Existing Condition (Base)	Scenario 2 (Optimization + Barrier)	Effectiveness (%)
Average Delay (sec/veh)	22.63	28.01	-23.77%
Level of Service (LOS)	C	D	Reduced

Source: Microsimulation Analysis Results (2026)

The implementation of Scenario 2 shows that the average delay value increased by 22.77% because this physical restriction creates a load concentration at the traffic flow merging area (merging) on the existing official route. This increase in delay proves that closing access without providing a more efficient alternative route tends to only relocate the saturation point to another location. In accordance with the Engineering the Behavior theory, closing dangerous access must indeed be done, but it must be supported by geometric design capable of accommodating vehicle volume flexibly so as not to trigger "route fatigue" in the long term (Ajzen, 1991; Mulyono, 2012).

4.8.4.Scenario 3: New Lane and Combined Solution 2

Scenario 3 is a permanent solution that integrates traffic signal optimization with the provision of an alternative traffic movement route through the East Arm Roundabout toward the merging B direction and Boulevard Street. This design is intended to simplify the rider's decision point by providing direct access toward Gempol Street and the Merging B Roundabout without having to add to queue loads at the main intersection.



Figure 7. VISSIM Visualization of Scenario 3

Table 12. Comparison of Traffic Performance Parameters (Base vs. Solution 3)

Performance Parameter	Existing Condition (Base)	Scenario 3	Effectiveness
Average Delay (sec/veh)	22.63	20.34	10.12%
Level of Service (LOS)	C	C	Stable

Source: Microsimulation Data Processing Results (2026)

Based on the modeling visualization in Scenario 3, it can be seen that geometric arrangement through the new lane and roundabout has successfully separated the rider's decision point. Visually, this design demonstrates physical flow separation with the use of permanent barriers, ensuring that wrong-way maneuvering (WWD) cannot physically be

performed. In addition, it demonstrates orderly flow in the vehicle circulation heading to Gempol Street because it is directly accommodated without having to cut across the main flow on Jalan Sutera, so that the wrong-way maneuvering (WWD) problem can be eliminated through geometric design.

4.9. Synthesis of Results and Discussion of Traffic Management

This research dissects three different approaches, each with contrasting technical characteristics and sociological impacts.

4.9.1. Comparison of Effectiveness Across Scenarios

This research dissects three different approaches, each with contrasting technical characteristics and sociological impacts. Scenario 1 (Signal Optimization) provides instant improvement in green time distribution and reduces delay at the main approach without additional implementation costs, but it has not addressed the root safety problem because the physical gap for committing WWD remains open. This scenario only suppresses symptoms but has not cured the source of the problem. Scenario 2 (Physical Barrier Installation) successfully provides a high safety guarantee through total severance of illegal access, yet it creates a relocation of the saturation point. Because no adequate alternative route is provided, the entire burden shifts to the existing U-turn, triggering secondary friction. Scenario 3 (Implementation of New Route through Roundabout) represents the most optimal solution combining optimal delay reduction (delay of 20.34 seconds) and providing a high safety guarantee through the severance of illegal access. This strategy proves that distributing volume load to the new road before entering the main intersection is the most effective bottleneck engineering approach. However, it requires infrastructure investment (road and roundabout construction) that consumes the area's capital expenditure (CAPEX).

4.9.2. Rationality of Traffic Management: Efficiency vs. Absolute Distance

The circulation optimization in Scenario 3 proves that the efficiency of the traffic system is not solely determined by absolute travel distance, but is dominated by the smoothness of flow at circulation nodes. From a traffic management perspective, providing a direct route is a crucial strategy to create stable orderly flow (Mulyono et al., 2012). The benefit of a 10.12% delay reduction automatically eliminates the psychological urgency for riders to take speculative wrong-way actions.

4.9.3. Sociological Legitimacy and Systemic Compliance

Viewed from a sociological perspective, this traffic diversion of approximately ±1.20 km receives strong legitimacy through the psychological threshold profile of road users. Questionnaire data shows that the majority of respondents (based on the theory of Perceived Behavioral Control) consider a detour route to be rational up to the critical point of 1,000 meters. The 200-meter distance difference from this standard represents a reasonable and very acceptable trade-off for riders as compensation for the elimination of fatal conflicts and static queuing on the road. Riders will psychologically choose the more efficient route, especially in terms of time (Sirait & Santoso, 2024). Through the integration of geometric design aligned with the tolerance limits of human psychology, Scenario 3 can transform active violating behavior into systemic compliance (Systemic Compliance), creating a road area that is safe, smooth, and safety-resilient (Zhang et al., 2024).

5. Conclusion

Based on the research results, wrong-way driving (WWD) violations in the Alam Sutera area represent conscious behavior driven by time efficiency considerations, not by ignorance of the rules, with the rider's detour distance tolerance threshold standing at approximately 1,000 meters. When the alternative distance exceeds this threshold, the intention to violate increases significantly. From a safety perspective, the Swedish Traffic Conflict Technique (TCT) analysis shows that the WWD lane carries a very high risk, with 80% of conflicts classified as serious and an average Time-to-Accident value of only 0.7 seconds, placing it as a fatally risky zone. The PTV VISSIM microsimulation results on mitigation scenarios show that the combined approach of providing an alternative route and installing physical barriers (barrier) is most effective in creating a self-enforcing road, that is, a condition in which the opportunity for violations is eliminated through design. In addition to improving safety, this scenario is also capable of improving traffic performance by reducing vehicle delay and creating more orderly flow (orderly flow).

Practically, area managers are advised to implement a phased strategy, starting from traffic signal cycle time optimization in the short term, installation of physical barriers at illegal access points during peak hours in the medium term, and the construction of new lanes and roundabouts as a long-term solution. The police and transportation department also need to adopt an enforcement by design approach, that is, ensuring that every route with a U-turn distance exceeding the psychological threshold of 1,000 meters is equipped with geometric engineering that prevents violations. Academically, future research is advised to develop methods with the integration of AI-based Automated Traffic Conflict Technique technology for continuous conflict analysis, as well as expanding the study to examine the influence of external factors such as economic pressure from logistics systems or online motorcycle taxi services on riders' risk-taking tendencies.

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