

OPTIMIZATION OF SIGNALIZED INTERSECTION PERFORMANCE USING THE IHCM 1997 APPROACH IN AN URBAN INDUSTRIAL AREA: A CASE STUDY OF THE DAM MUKA KUNING INTERSECTION, BATAM

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Abstract

Traffic congestion at signalized intersections in urban areas has become a critical issue as transportation activities increase due to economic growth and urbanization. The Dam Muka Kuning intersection in Batam City is one of the strategic intersections located within an industrial zone, characterized by high traffic volumes and significant vehicular movement complexity. This study aims to evaluate the performance of the signalized intersection based on capacity parameters and degree of saturation, as well as to formulate signal timing optimization strategies to improve the intersection's level of service. The method employed is a quantitative approach based on the 1997 Indonesian Highway Capacity Manual (IHCM), utilizing traffic volume data obtained from field surveys during peak hours. The analysis encompasses saturated flow, capacity, flow ratio, and degree of saturation for each intersection approach. The findings indicate that the intersection operates under oversaturated conditions, with degree of saturation (DS) values reaching 3.81 at the south approach, 2.55 at the west approach, and 1.88 at the east approach all of which substantially exceed the ideal threshold ($DS \leq 0.85$). These conditions signify a significant deterioration in the level of service, marked by extensive queue lengths and high delays. The predominant factors contributing to congestion include high side friction, ingress and egress activities associated with the industrial zone, and signal timing configurations that have yet to adapt to traffic flow fluctuations. To enhance intersection performance, this study proposes a signal timing optimization strategy based on actual traffic conditions through the adjustment of cycle times and green time distribution. Furthermore, side friction management and geometric improvements at the intersection are necessary to support the effectiveness of traffic engineering measures. The findings of this study offer a practical contribution to the management of signalized intersections in urban areas experiencing high levels of saturation.

Keywords: *Signalized Intersection, Degree Of Saturation, Capacity, Signal Optimization, IHCM 1997*

INTRODUCTION

The rapid growth of urban areas, particularly in regions driven by industry and commerce, has direct consequences on increased mobility and transportation demand. Batam City, as one of Indonesia's strategic economic growth centers located in close proximity to Singapore, has experienced significant development in the industrial, trade, and service sectors. This condition has driven population growth and high movement activity, thereby directly affecting the performance of the urban transportation system. Alongside this growth, traffic issues such as congestion, delays, and declining road levels of service have become increasingly complex. One of the critical points of these issues lies at signalized intersections, which serve as conflict points for traffic flows. Suboptimal intersection performance leads to increased delays, longer queue lengths, as well as higher fuel consumption and vehicle emissions, ultimately affecting the efficiency of the overall transportation system. The Dam Muka Kuning intersection is one of the strategic intersections in Batam City, situated in an area with high-intensity activities encompassing an industrial zone, shopping centers, and public service facilities. The high traffic volumes during peak hours, both in the morning and afternoon, result in saturated and even oversaturated conditions, characterized by significant vehicle queue lengths and delays at each intersection approach. This issue is further compounded by high side friction, including on-street parking activities, vehicles entering and exiting the industrial zone, and the presence of commercial facilities surrounding the intersection. Additionally, suboptimal traffic signal timing also

serves as a contributing factor to the deterioration of intersection performance. Within the context of traffic engineering, evaluating the performance of signalized intersections is essential to determine the level of service and to identify appropriate mitigation strategies. The commonly adopted approach in Indonesia is based on the 1997 Indonesian Highway Capacity Manual (IHCM), which enables quantitative analysis of capacity, degree of saturation, and signal timing configurations. Therefore, this study aims to evaluate the performance of the Dam Muka Kuning intersection based on capacity and degree of saturation parameters, as well as to formulate alternative traffic signal optimization measures to improve the intersection's level of service. The findings of this study are expected to contribute to urban traffic planning and management, particularly in areas characterized by dense and complex traffic conditions.

LITERATURE REVIEW

The performance of signalized intersections serves as one of the primary indicators in evaluating urban transportation systems, particularly in areas with high levels of mobility (Ahmida et al., 2023). As conflict points for traffic flows, intersections play a critical role in determining the smooth movement of vehicles. Intersection performance is generally measured using parameters such as capacity, delay, queue length, and degree of saturation. The capacity of signalized intersections is influenced by various factors, including approach width, side friction, vehicle composition, and signal timing configuration (Cao & Zhang, 2023). The degree of saturation (DS) is the principal indicator for assessing the level of service at an intersection, where a DS value of ≤ 0.85 indicates stable conditions, while a DS value exceeding 1.00 signifies saturated to oversaturated conditions (Putri et al., 2025).

Several previous studies have demonstrated that congestion at urban intersections is generally caused by an imbalance between traffic volume and road capacity, as well as signal timing that is not adaptive to actual traffic conditions (Tong et al., 2025). Furthermore, side friction factors such as on-street parking, commercial activities, and access points to and from adjacent areas also contribute to the decline in intersection performance (Artifiani Havianto et al., 2025). Within the context of traffic engineering, signal timing optimization represents one of the effective solutions for enhancing capacity and reducing delays (Zhao & Su, 2024). The adjustment of cycle times and green time distribution based on actual traffic flow conditions has been proven to improve the operational efficiency of intersections, particularly in areas characterized by dense traffic such as industrial zones (Huang et al., 2021). Based on the foregoing discussion, this study focuses on evaluating the performance of signalized intersections using the IHCM 1997 approach, as well as formulating signal timing optimization strategies to improve the intersection's level of service.

METHOD

1. Research Design

This study employs a descriptive-analytical quantitative approach aimed at evaluating the performance of a signalized intersection based on traffic operational parameters. The analysis is conducted using the 1997 Indonesian Highway Capacity Manual (IHCM) method as the primary reference for calculating intersection capacity, saturated flow, and degree of saturation. This approach was selected because the IHCM is a nationally recognized standard commonly used in intersection performance analysis in Indonesia and is capable of empirically representing urban traffic conditions.

2. Study Location and Duration

The study was conducted at the Dam Muka Kuning intersection, Batam City, which is a three-leg signalized intersection characterized by high traffic volumes. This location was selected due to the following reasons:

- a. It is situated within an industrial zone (Batamindo)
- b. It provides access to a shopping center (Panbil Mall)
- c. It experiences high traffic volumes during peak hours

Data collection was carried out on weekdays, focusing on:

- a. Morning peak hour (08:00–09:00 Western Indonesian Time)
- b. Afternoon peak hour (18:00–19:00 Western Indonesian Time)

3. Types and Sources of Data

This study utilizes two types of data:

- a. Primary Data

Primary data were obtained through direct field surveys, encompassing:

- 1) Traffic volume per approach (pcu/hour)
 - 2) Vehicle composition
 - 3) Left-turn and right-turn movements
 - 4) Intersection geometric conditions (approach width)
 - 5) Side friction (parking, roadside activities)
- b. Secondary Data
- Secondary data were obtained from relevant agencies, including:
- 1) Population data of Batam City
 - 2) Average daily traffic (ADT) data

4. Data Collection Techniques

Data collection was conducted using the traffic counting survey method, which involves recording the number of vehicles passing through the intersection at specified time intervals. Observations were carried out manually at each intersection approach, with vehicle classification converted into passenger car units (pcu).

In addition, the following were also conducted:

- a. Measurement of approach road widths
- b. Observation of side friction activities
- c. Identification of supporting facilities (U-turns, area access points)

5. Research Variables

The variables used in this study consist of:

- a. Primary Variables
 - 1) Traffic volume (Q)
 - 2) Intersection capacity (C)
 - 3) Saturated flow (S)
 - 4) Degree of saturation (DS)
- b. Supporting Variables
 - 1) City size adjustment factor (F_CS)
 - 2) Side friction factor (F_SF)
 - 3) Parking factor (F_P)
 - 4) Right-turn factor (F_RT)
 - 5) Left-turn factor (F_LT)
 - 6) Cycle time (c)
 - 7) Green time (g)

6. Data Analysis Procedure

Data analysis was conducted in stages based on the IHCM 1997 method as follows:

- a. Calculation of Base Saturated Flow (S_0)

The base saturated flow is calculated based on the effective approach width.

$$S_0 = 600 \times W_e$$

- b. Adjusted Saturated Flow (S)

The saturated flow is adjusted using correction factors.

$$S = S_0 \times F_{CS} \times F_{SF} \times F_G \times F_P \times F_{RT} \times F_{LT}$$

- c. Flow Ratio Calculation (FR)

$$FR = \frac{Q}{S}$$

- d. Intersection Flow Ratio Calculation (IFR)

$$IFR = \sum FR_{crit}$$

- e. Cycle Time Calculation (c)

The cycle time is calculated based on:

$$c = \sum g + LTI$$

- f. Capacity Calculation (C)

$$C = S \times \frac{g}{c}$$

g. Degree of Saturation Calculation (DS)

$$DS = \frac{Q}{C}$$

7. Intersection Performance Evaluation Criteria

Intersection performance is evaluated based on the degree of saturation (DS) value with the following criteria:

- $DS \leq 0.85 \rightarrow$ stable condition (good)
- $0.85 < DS \leq 1.00 \rightarrow$ approaching saturation
- $DS > 1.00 \rightarrow$ saturated to oversaturated condition

8. Research Stages

In general, the stages of this study include:

- Identification of traffic issues
- Field data collection
- Data processing based on the IHCM 1997
- Intersection performance analysis
- Evaluation and interpretation of results
- Formulation of improvement recommendations

RESULT

1. Traffic Volume

Volumes were taken from the highest density levels on weekdays:

- South direction, Jendral S. Parman road: 2,910.10 pcu/hour, recorded on Tuesday morning from 08:00–09:00
- East direction, Ahmad Yani road: 3,082.90 pcu/hour, recorded on Tuesday morning from 08:00–09:00
- West direction, R. Suprpto road: 2,912.30 pcu/hour, recorded on Tuesday afternoon from 18:00–19:00

Left-turn vehicle ratio (P_{LT}) = LT (pcu/hour) / Total (pcu/hour)

Right-turn vehicle ratio (P_{RT}) = RT (pcu/hour) / Total (pcu/hour)

From direct field observations, the following data were obtained:

- South Direction $P_{LT} = 960 / 2,910.10 = 0.33$ $P_{RT} = 894 / 2,910.10 = 0.30$
- West Direction $P_{RT} = 1,023.52 / 3,082.59 = 0.33$
- The east direction has channelization; therefore, it has no turning ratio.

2. Base Saturated Flow (S_0)

The base saturated flow at the Dam Muka Kuning intersection is calculated using the formula:

$$S_0 = 600 \times W_e \text{ (pcu/green hour)}$$

The results are as follows:

- South Direction / South Approach $S_0 = 600 \times 7 \text{ meters} = 4,200 \text{ pcu/green hour}$
- East Direction / East Approach $S_0 = 600 \times 7 \text{ meters} = 4,200 \text{ pcu/green hour}$
- West Direction / West Approach $S_0 = 600 \times 7 \text{ meters} = 4,200 \text{ pcu/green hour}$

3. City Size Adjustment Factor (FCS)

Based on population data for Batam City obtained from the BPS (Central Bureau of Statistics) website, the population of Batam City in 2017 was 1,283,196 inhabitants. Therefore, according to Table 2.7, the F_{CS} value used is 1.0.

Table 2.7 City Size Adjustment Factor (F_{CS}) Values

City Size (Million inhabitants)	City Size Adjustment Factor
< 1,0	0,86
0,1-0,5	0,9
0,5-1,0	0,94
1,0-3,0	1
> 3,0	1,04

Source: Indonesian Highway Capacity Manual 1997

4. Side Friction Adjustment Factor (FCSF)

From Table 2.6 and based on field survey results, the side friction level is classified as very high (VH) with an effective shoulder width (WS) of 1 meter. Therefore, the FSF value used is 0.88.

5. Gradient Factor (FG)

For the current study location, the gradient is 0%; therefore, the gradient factor FG value obtained is 1.0.

6. Parking Adjustment Factor (FP)

The parking adjustment factor (FP) is determined based on the distance from the stop line to the first parked vehicle and the approach width (WA). From the analysis, the following data were obtained:

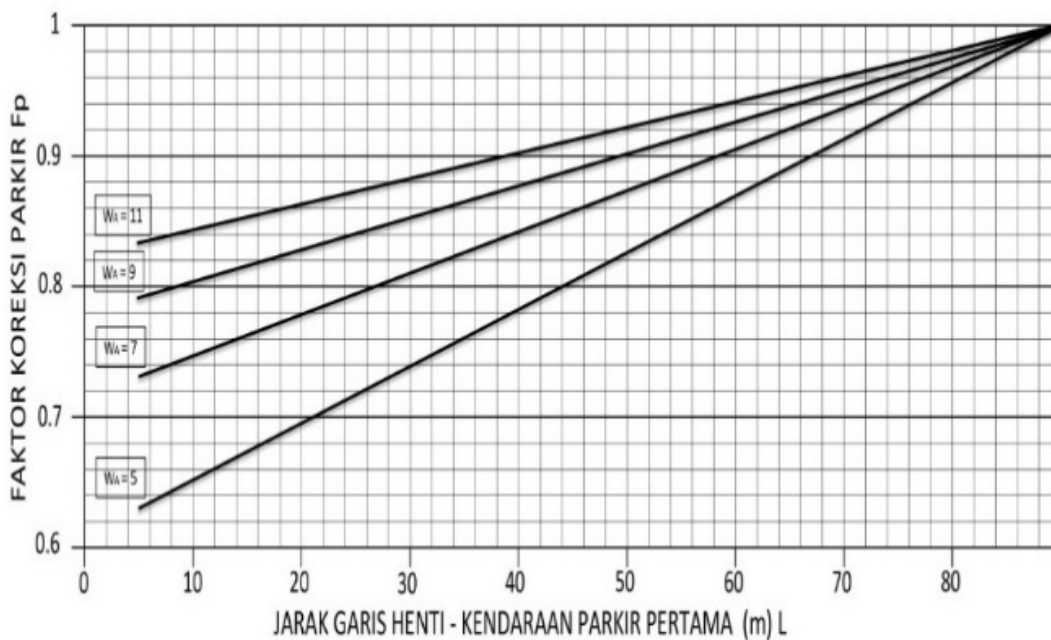


Figure 4.3 Parking Adjustment Factor Graph

- a. South approach, parking distance = 32 m (FP) = 0.85
- b. West approach, parking distance > 100 m (FP) = 1.0
- c. East approach, parking distance > 100 m (FP) = 1.0

7. Right-Turn Adjustment Factor (FRT)

The right-turn adjustment factor (FRT) is determined using the formula ($FRT = 1.0 + PRT \times 0.26$), and from the calculations, the following results were obtained:

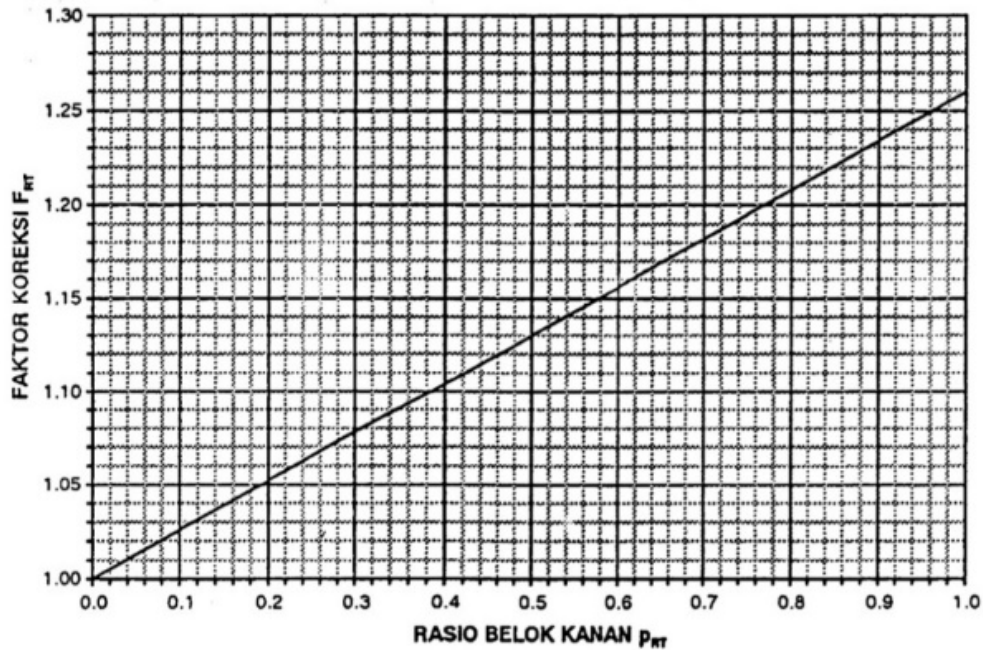


Figure 4.4 Right-Turn Ratio Factor Graph

- a. South approach, $F_{RT} = 1.0 + 0.30 \times 0.26 = 1.078$
- b. West approach, $F_{RT} = 1.0 + 0.33 \times 0.26 = 1.086$
- c. East approach, $F_{RT} = 1.0 + 0 \times 0.26 = 1.00$

8. Left-Turn Adjustment Factor (F_{LT})

The left-turn adjustment factor (F_{LT}) is determined using the formula ($F_{LT} = 1.0 - P_{LT} \times 0.16$), and from the calculations, the following results were obtained:

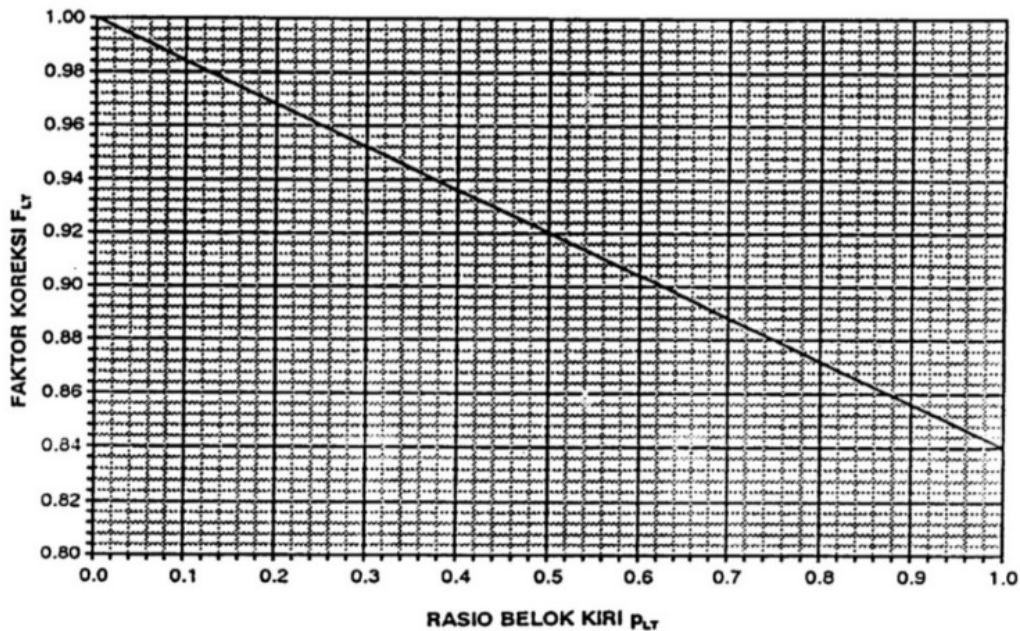


Figure 4.5 Left-Turn Ratio Factor Graph

- a. South approach, $FLT = 1.0 - 0.33 \times 0.16 = 0.947$
- b. West approach, $FLT = 1.0 - 0.00 \times 0.16 = 1.00$
- c. East approach, $FLT = 1.0 - 0 \times 0.16 = 1.00$

9. Adjusted Saturated Flow

The adjusted saturated flow is calculated using the formula ($S = S_0 \times FCS \times FSF \times FG \times FP \times FRT \times FLT$ pcu/green hour) and is computed as follows:

- South Direction $S = 4,200 \times 1.0 \times 0.88 \times 1.0 \times 0.85 \times 0.947 \times 1.0 = 2,975.09$ pcu/green hour
- East Direction $S = 4,200 \times 1.0 \times 0.88 \times 1.0 \times 1.0 \times 1.086 \times 1.0 = 4,013.86$ pcu/green hour
- West Direction $S = 4,200 \times 1.0 \times 0.88 \times 1.0 \times 1.0 \times 1.0 \times 1.0 = 3,696$ pcu/green hour

10. Flow Ratio (FR)

The flow ratio relative to the saturated flow (Q/S) for each approach:

$$FR = Q / S$$

- South Direction $= 2,910.10 / 2,975.09 = 0.97$
- West Direction $= 3,082.90 / 3,696 = 0.83$
- East Direction $= 2,912.30 / 4,013.86 = 0.72$

11. Intersection Flow Ratio (IFR)

The intersection flow ratio (IFR) is determined using the formula: $IFR = \Sigma(FR_{crit})$

From the calculations, the following result was obtained:

$$IFR = \Sigma(FR_{crit})$$

$$IFR = (0.97 + 0.83 + 0.72)$$

$$IFR = 2.52$$

12. Phase Ratio (PR)

The phase ratio (PR) is determined using the formula: $PR = FR_{crit} / IFR$

From the calculations, the following results were obtained:

- East approach, $PR = 0.72 / 2.52 = 0.28$
- South approach, $PR = 0.97 / 2.52 = 0.38$
- West approach, $PR = 0.83 / 2.52 = 0.32$

13. Pre-Adjustment Cycle Time (c_{ua})

The pre-adjustment cycle time (c_{ua}) is determined using the formula:

$$c_{ua} = (1.5 \times LTI + 5) / (1 - IFR)$$

From the calculations, the following result was obtained:

$$c_{ua} = (1.5 \times 5.2 + 5) / (1 - 2.52) = -8.421 \text{ seconds}$$

14. Green Time (g)

The green time is adjusted according to field conditions, yielding the following:

- East approach, $g = 40$ seconds
- South approach, $g = 51$ seconds
- West approach, $g = 60$ seconds

15. Adjusted Cycle Time (c)

The adjusted cycle time (c) is determined using the formula:

$$c = \Sigma g + LTI$$

From the calculations, the following result was obtained:

$$c = 151 + 5.2 = 156.2 \text{ seconds} \approx 156 \text{ seconds}$$

16. Capacity of Each Approach (C)

The capacity of each approach (C) is determined using the formula:

$$C = S \times g / c$$

From the calculations, the following results were obtained:

- South approach, $C = 2,975.09 \times (40 / 156) = 762.84$
- West approach, $C = 3,696 \times (51 / 156) = 1,208.30$
- East approach, $C = 4,013.86 \times (60 / 156) = 1,543.79$

17. Degree of Saturation (DS)

The degree of saturation is determined using the formula:

$$DS = Q / C = (Q \times c) / (S \times g)$$

From the calculations, the following results were obtained:

- a. South approach, degree of saturation = 3.81
- b. West approach, degree of saturation = 2.55
- c. East approach, degree of saturation = 1.88

CONCLUSION

1. Findings

Based on the analysis and discussion of the traffic analysis results at the Dam Muka Kuning intersection, the following conclusions can be drawn:

- a. Vehicle volumes at the Dam Muka Kuning intersection have exceeded the upper limits of road capacity.
Vehicle Volume > Vehicle Capacity
 - 1) Vehicle volume in the south direction = 2,975.09 > 762.84
 - 2) Vehicle volume in the west direction = 3,696 > 1,208.30
 - 3) Vehicle volume in the east direction = 4,013.86 > 1,543.79
- b. The level of service has reached the highest threshold of the degree of saturation, particularly on Tuesdays during the morning and afternoon periods. The degree of saturation calculations for each leg are as follows:
 - 1) Degree of saturation in the south direction = 3.81 > 0.85
 - 2) Degree of saturation in the west direction = 2.55 > 0.85
 - 3) Degree of saturation in the east direction = 1.88 > 0.85
- c. Several factors contribute to congestion at the Dam Muka Kuning intersection, including:
 - 1) Side friction in the west direction is classified as high due to irregular parking.
 - 2) There is no left-turn channelization on the south leg.
 - 3) On the west side, there is a main entrance and exit gate to the Batamindo Industrial Park integrated zone, along with two U-turn facilities in close proximity.
 - 4) On the east side, there is an entrance to the Panbil Mall shopping center.

2. Recommendations

The proposed alternative solutions include the following:

- a. Reduce the considerably high side friction by prohibiting vehicles from stopping on the roadway and road shoulders, particularly public transport vehicles that stop on the roadway, and by enforcing passenger boarding and alighting activities at designated bus stops.
- b. Add one additional lane from the Batu Aji direction toward Batam Center and from the Batam Center direction toward Batu Aji, or alongside the police post.
- c. Prohibit street vendor activities along the roadside, as they disrupt road users.
- d. The first U-turn in the direction of Batu Aji should be closed, as its distance to the Panbil intersection is too close approximately only ±50 meters whereas the recommended spacing between U-turns is between 400 to 800 meters.

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