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Analysis and Performance Improvement of a Four-Leg Unsignalized Intersection (Case of study: Duta Berlian Intersection, Dramaga, Bogor)

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Abstract: The Duta Berlian intersection near IPB University, Dramaga, Bogor experiences severe traffic congestion due to traffic volumes exceeding its capacity, high roadside friction, and the absence of traffic light. This study aims to evaluate the performance of the existing intersection and assess several improvement scenarios to improve intersection's capacity and level of service (LOS). Traffic volume surveys were carried out using the Classified Turning Movement Counting (CTMC) method during morning and evening peak hours, followed by analysis of capacity, degree of saturation (DS), delay, and queue probability calculations. The 2023 Indonesian Highway Capacity Manual (PKJI 2023) and Ministry of Transportation Regulation No. 96/2015 were used as the analysis method and LOS classification. The analysis showed that the existing condition has DS of 1.08, average delay of 23.3 sec/PCU, queue probability of 93.23%, and LOS C. Four scenarios were tested: approach widening, conversion to a signalized intersection, application of a four-phase signal with right-turn separation, and addition of a left turn on red (LTOR) lane. The optimal scenario combined a minimum widening of 2 m with a four-phase signal and LTOR, reducing DS to 0.70, delay to 12–15 sec/PCU (LOS B). In conclusion, conversion to a signalized intersection with geometric redesign and traffic flow management significantly improves intersection performance and is recommended to be equipped with yellow box junctions, markings, and signage as a medium-term solution. For a long-term solution, a grade-separated intersection is recommended.

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1. Introduction

Road infrastructure development is an important element in supporting transportation for daily life needs. The Dramaga area in Bogor, especially near the IPB University campus, has experienced a significant increase in traffic activity due to the growth of IPB University as an educational center and the increasing number of residents and motorized vehicles. Duta Berlian intersection is the intersection that connects the IPB campus ring road, Dramaga Ring Road, and Dramaga Raya road, and plays as an important role to connect the surrounding residential area and other activities. These areas are affected by the high population growth rate of Bogor Regency which in 2024 reached 5,664,537 people, as well as vehicle growth of 7.51% per year with a total of 1,763,241 units [1]. This high population and vehicles ownership have triggered severe traffic congestions in this area.

Traffic congestion in Bogor Regency is generally caused by vehicle volumes exceeding road capacity, road user behavior that violates regulations, and inadequate infrastructure. Other factors such as illegal parking, traffic violations, suboptimal intersection or traffic light systems [2], and a lack of alternative routes also worsen the situation [3], [4], [5], [6]. The impact of congestion is reflected in the decline in the level of traffic service (*Level of Service/*LOS) according to Minister of Transportation Regulation No. 96 of 2015, which measures the quality of traffic flow from LOS A (free flow) to LOS F (severe congestion) [7]. This condition is often found around the IPB University Dramaga campus area which has complex traffic activities, exacerbated by the high intensity of academic activities, student organizations, campus events, as well as commercial and residential activities in the surrounding area.

One of the points that frequently experiences congestion is the Duta Berlian intersection, a four-leg unsignalized intersection that often faces high traffic conflicts during rush hour. According to PKJI 2023, unsignalized intersections with high volumes tend to have a degree of saturation approaching or exceeding the limit, with an average delay of 8–10 seconds per vehicle during peak hours [8]. Previous studies have stated that adding geometry or converting to a signalized intersection can improve traffic flow efficiency [9]. Improvements to this intersection need to be in line with the Bogor Regency Spatial Plan (RTRW) 2024–2044 which establishes Dramaga Raya road as the main corridor connecting strategic areas such as IPB University, residential areas, and trade [10].

Duta Berlian intersection, as a strategic intersection faces problems such as malfunctioning traffic light, road medians that are opened and closed by unauthorized parties, and un-regulated traffic flow. Based on this problem, this study tends to conduct the intersection performance evaluation based on indicators of service level, degree of saturation, and traffic delays, as well as formulating recommendations for improvements. With a data-driven approach, improvements to this intersection are expected to improve smooth mobility and support a sustainable transportation system in the IPB University Dramaga area.

2. Method

2.1. Location and Materials

The location of the intersection that is the object of research is located at Duta Berlian intersection, Bogor Regency, West Java at coordinates 6°33'55.89"S; 106°44'7.61"E. The tools and materials used in this series of research include smartphones, stopwatches, manual calculators, measuring tapes, stationery, traffic applications counter, Google Earth application, Microsoft Excel data processing application, and AutoCAD 2024 2D drawing application. The data used in this study are intersection geometric, traffic flow speed and volume passing through the intersection. Other data used are environmental data and maps of Duta Berlian intersection. The reference standards used in this study include the Indonesian Road Capacity Guidelines (PKJI 2023) by the Directorate General of Highways, Ministry of PUPR (Public Works and Public Housing), Regulation of the Minister of Transportation of the Republic of Indonesia Number 96 of 2015 concerning Guidelines for the Implementation of Traffic Management and Engineering Activities, and Regulation of the Minister of Public Works and Public Housing of the Republic of Indonesia Number 5 of 2023 regarding the Technical Requirements for Roads and Road Technical Planning.

2.2. Work procedures

The initial stages of this research involved a literature review to understand the theoretical basis and context of the research, observations of busy intersection conditions, and the subsequent collection of relevant primary and secondary data. Primary data of traffic volume was collected manually with the help of a traffic counter application. Morning (06:00-09:00) and afternoon (15:00-18:00) traffic data are used for initial analysis, including identification of intersection types and calculation of traffic volume during peak hours. The intersection capacity (C) is calculated to analyze the characteristics of traffic, which includes determining the value of the DS, delay (T), and queue probability (Pa) or the number of stopped vehicles. These parameters are the main indicators in evaluating the intersection's level of service.

2.3. Input Data Analysis

The existing intersection geometry data is converted into a geometry sketch using the AutoCAD application. The major data for the intersection analysis is the traffic flow data in the form of vehicles/hour at design hour. The PCU (passenger car unit) factor is calculated based on the traffic flow composition data of passenger cars (LV), heavy vehicles (HV), and motorcycles (MC) using the PCE (passenger car equivalent) value. The additional data such as the date, month, year, detailed location and names of the major and minor roads are also provided.

2.4. Capacity Analysis of Existing Intersections (Unsignalized)

The existing unsignalized intersection capacity (C) is calculated based on the total inflow from all intersection legs, using a formula that multiplies the basic capacity (C_0) by correction factors to adjust actual conditions to ideal conditions following **Equation 1**.

$$C = C_0 \times F_{AW} \times F_M \times F_{CS} \times F_{SF} \times F_{LT} \times F_{RT} \times F_{Rmi} \quad (1)$$

With C_0 is the basic capacity of the intersection (PCU/hour), while F_{AW}, F_M, F_{CS}, F_{SF}, F_{LT}, F_{RT}, and F_{Rmi} are correction factors of approaching lane width, median type, city size, side friction, traffic left turn ratio, traffic right turn ratio, and minor road traffic ratio, respectively.

2.5. Design Intersection Capacity Analysis (Signalized)

The signalized intersection capacity (C) is calculated as the capacity of each approach carried out separately. One signalized intersection leg can consist of 1 one or more approaches and phase settings, that are calculated using **Equation 2**.

$$C = J \times \frac{GT}{Ct} \quad (2)$$

Where C is the signalized intersection capacity (PCU/hour), J is traffic saturation (PCU/hour), GT is total green time in one cycle (seconds), and Ct is Cycle time (seconds). The traffic saturation (J) is calculated based on the basic traffic saturation calculation (J_0) multiplied by correction factors to adjust the actual conditions to ideal conditions. This calculation follows **Equation 3**.

$$J = J_0 \times F_{HS} \times F_{UK} \times F_G \times F_P \quad (3)$$

where:
F_{SF} = Correction factor J_0 due to side frictions in the road environment
F_{CS} = Correction factor J_0 related to city size
F_S = Correction factor J_0 due to longitudinal slope of the approach
F_P = Correction factor J_0 due to the distance of the approach stop line to the first parked vehicle

2.6. Intersection Performance Analysis

As suggested in PKJI 2023, the intersection plan is accepted if Dj ≤ 0.85. In the case where Dj > 0.85, the planned capacity is considered inadequate that requires a redesign or increase the intersection. The degree of saturation, DS, is calculated using **Equation 4**.

$$DS = \frac{q}{C} \quad (4)$$

Where DS is the degree of saturation, C is the intersection capacity (PCU/hour), and q is traffic flows entering the intersection (PCU/hour).
The intersection's LOS is determined based on the delay value (T), in accordance with the provisions contained in the Minister of Transportation Regulation No. 96 of 2015 concerning Guidelines for the Implementation of Traffic Management and Engineering Activities. Thus, the analysis in the intersection

is conducted to obtain the main goal parameter, delay (T), to be able to conclude intersection's level of service. The delay consists of traffic delay (D_T) and geometric delay (D_G). The degree of saturation (DS) from the previous calculation is one of the main input parameters for determining the delay. The delay at an unsignalized intersection is calculated following PKJI 2023.

3. Results and Discussion

3.1. Geometric Profile of the Intersection

The Duta Berlian intersection is an unsignalized intersection with 4 legs located on Jalan Raya Dramaga as a major road with the Dramaga Ring Road and the IPB University Dramaga Campus Ring Road as minor roads. The geometric and approach identification at the Duta Berlian intersection is presented in **Table 1**.

Table 1. Geometric parameter of Duta Berlian intersection for each approach

Section	Approacher	Road Width	Road Type	Lane Width	Side Friction
Dramaga Raya road (Towards IPB)	A (West)	8	2/2 TT	4	Moderate
IPB University campus ring road	B (North)	6	2/2 TT	±3	Moderate
Dramaga Raya Road (To Bubulak)	C (East)	8	2/2 TT	4	Moderate
Dramaga ring road	D (South)	7	2/2 TT	±3.5	Moderate

Based on the classification, Duta Berlian intersection is classified as a type 422 intersection (4 legs, 2 major road lanes and 2 minor road lanes). Side frictions at this intersection are classified as moderate, because the traffic flow entering and exiting the intersection is quite disrupted, especially by vehicles entering and exiting the road, public transportation stops, and commercial activities or shops on the side of the road, thus increasing the activity of vehicles entering and exiting. There are traffic lights that are not functioning, faded road markings, and the absence of signs make the road not meet the standards of roadworthiness or in this case, a national road. **Figure 1** shows the profile of the studied intersection.

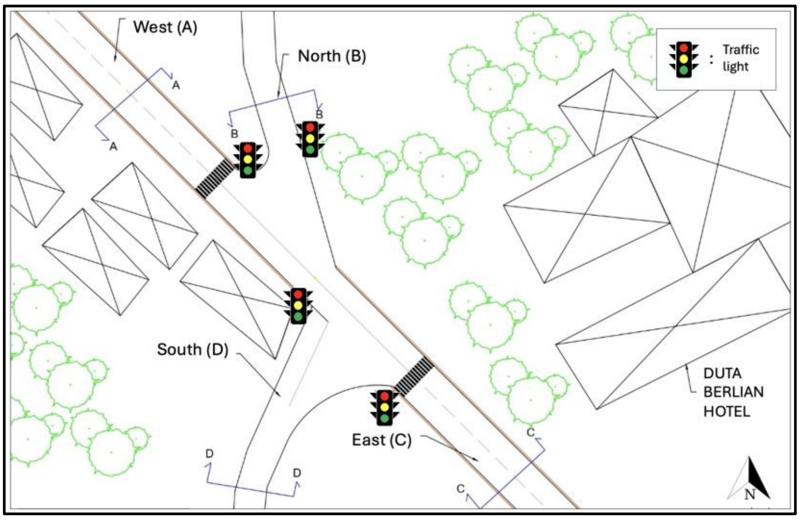

Figure 1. Duta Berlian intersection geometry

3.2. Intersection Traffic Volume

Traffic volume at the intersection is calculated on each section at intervals of every fifteen minutes from all vehicles exiting and entering the intersection. Observations were made during two daily peak hours: 6:00–9:00 am and 3:00–6:00 pm, to capture traffic conditions during daily rush, busy hours. The data obtained was then classified based on vehicle types including motorcycle, heavy truck and buses, and normal light vehicles, and then converted into passenger car unit per hour (pcu/hour). The results of this conversion are presented in the form of a graph shown in **Figure 2.**

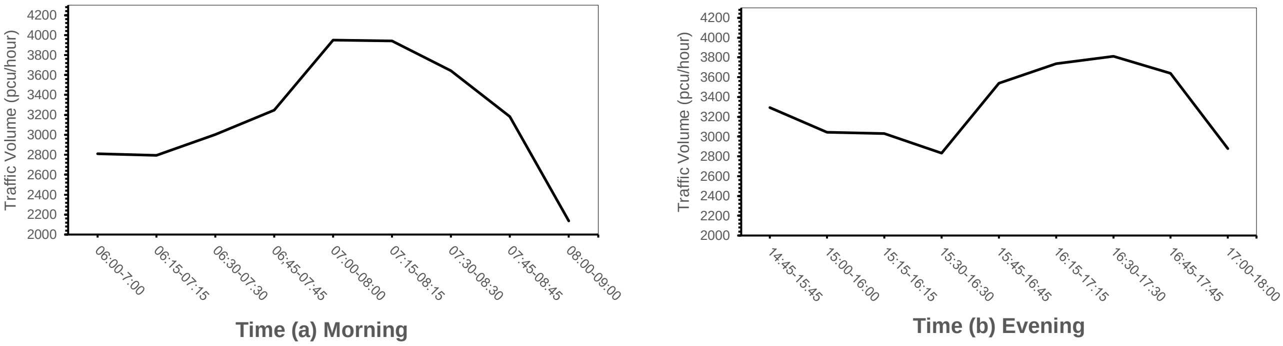

Figure 2. Traffic volume at Duta Berlian intersection in the morning (a) and evening (b)

Figure 2 shows that morning vehicle volume peaked between 7:00 and 8:00 am, reaching 3,949 PCU/hour. This spike reflects the high intensity of morning traffic. After this peak period, traffic volume decreased to 2,136 PCU/hour between 8:00 and 9:00 am. This decline then continued significantly until 9:00 am, signaling an easing of morning activity and the end of peak traffic hours.

In the afternoon, vehicle volume reaches its highest level between 4:30–5:30 PM, at 3,810 PCU/hour. This number indicates dense mobility during rush hour and after work and college hours. This condition begins to improve at 4:30–5:30 PM, where traffic volume drops to 2,877 PCU/hour, signaling the end of the afternoon rush hour and the return of normal traffic flow around the IPB University Dramaga area. These data show that the highest traffic volume occurs in the morning at 3,949 PCU/hour, which indicates a higher traffic activity in the Duta Berlian intersection, compared to the afternoon.

3.3. Existing Intersection Analysis

Based on the calculation of C0 and all correction factors, the intersection capacity is 3668 PCU/hour in the morning and 3766 PCU/hour in the afternoon. The morning intersection capacity is smaller because the morning intersection volume is larger, so to facilitate further analysis, only the intersection data will be used in the morning (7:00-8:00). Furthermore, the intersection performance analysis of saturation degree (DS), delay (T), and queue probability (Pa) is presented in **Table 2**.

Table 2 Performance of Duta Berlian intersection in the morning and evening

Time	q_{TOT} PCU/hour	Traffic performance								LOS
		DS	D_T	T_{LLma}	T_{LLmi}	T_G	$T=T_{LL}+T_G$	P_a		
Morning	3949.60	1.08	19.32	12.94	49.27	4.00	23.32	93.23	46.75	C
Afternoon	3810.83	1.01	15.54	10.82	30.65	4.00	19.54	81.50	41.14	C

Based on the calculation, the current level of intersection service based on DS > 1, then improvements need to be made to DS ≤ 0.85 and based on the current delay (T) value of > 15-25 seconds with a LOS value of C. The current intersection analysis shows that the Duta Berlian intersection is unable to accommodate traffic volume during peak hours. Dramaga raya road is categorized as a primary arterial road, so it is required to have a level of service in category A or at least B in accordance with the provisions of Ministerial Regulation Number 96 of 2015.

According to PKJI 2023, there are two alternative changes that can be considered, including increasing the width of the approach which can be done on approaches with critical DS, and prohibiting right-turn movements, where prohibiting one or more right-turn movements can usually increase capacity

[8]. Meanwhile, reducing side frictions such as illegal parking, pedestrian activity on the road, and slow vehicles can also increase intersection capacity [11].

3.4. Unsignalized Intersection Improvement Analysis – Scenario 1

The first improvement scenario is to increase the width of the approaching road section. Road widening is carried out approach B (North) from 6 to 8.5 meters to fulfill specifications according to Ministry Regulation No. 5 of 2023 [10]. Other approaches which are A (West) and C (East) can be widened to 10 meters to increase capacity and eliminate side friction. Another widening scheme is changing the major road to 12 meters and the minor to 10 meters. The results of the intersection improvement analysis compared to before the improvement are presented in **Table 3**.

Table 3 Performance of Duta Berlian intersection scenario 1

Scheme	Capacity (C) pcu/hour	Traffic performance								LOS
		D_S	D_T	T_{LLma}	T_{LLmi}	T_G	$T=T_{LL}+T_G$	P_a		
Existing	3668.49	1.08	19.32	12.94	49.27	4.00	23.32	93.23	46.75	C
Obstacle	3902.65	1.01	15.55	10.82	37.74	4.00	19.55	81.54	41.16	C
Width 1	4173.48	0.95	12.97	9.28	72.56	3.97	16.94	70.91	35.93	C
Width 2	4527.64	0.87	10.92	7.98	24.72	3.92	14.84	60.32	30.55	B

Table 3 shows that the existing condition of Duta Berlian intersection has a high degree of saturation (DS = 1.08) and a queue probability 93.23%, with a delay time 23.32 seconds and LOS F. The removal of side friction slightly improves the condition, but the widening scheme provides the most significant improvement with DS decreasing to 0.87, a queue probability of 60.32%, and a delay time of 14.84 seconds, indicating that the intersection geometry engineering is effective in improving traffic performance.

3.5. Analysis of Signalized Intersection Arrangements (Existing) – Scenario 2

The second improvement analysis is the improvement of the intersection from unsignalized to a signalized intersection. This scenario does not widen the existing intersection geometry lane. In this analysis, all types of signalized intersection phase arrangements are analyzed at intersections 4 with 2, 3, and 4 phases.

Based on the results of the intersection phase arrangement analysis, the typical 2-phase and 3-phase signalized intersection phase arrangements cannot be used to regulate the traffic of the Duta Berlian intersection. The results of the R_{AS} (Ratio of intersection traffic flow) analysis exceed the limit that can be calculated, namely $R_{AS} \leq 1$ [8]. Therefore, further analysis and design is needed to lower $R_{AS} < 1$. Based on PKJI 2023, increasing the width of the approach, changing the signal phase, and prohibiting right-turn movements can improve the traffic performance of the signalized intersection [12], [13].

In the analysis of the 4-phase signalized intersection, there is one 4-phase signalized intersection phase setting that can be used to regulate the Duta Berlian intersection by using the modified or optimized signalized 44C intersection phase setting by separating right turns on both roads in Phases 2 and 4 (44C2). The analysis of the signalized 44C2 intersection phase setting produces a R_{AS} of 0.93 with a phase cycle of 408 seconds resulting in a DS of 0.98 and a delay (T) of 92 seconds/PCU (LOS F) with the largest queue length (PA) on the eastern approach of 856.43 m. The following signal phase and the results of the signalized 44C2 intersection analysis are shown in **Figure 3**.

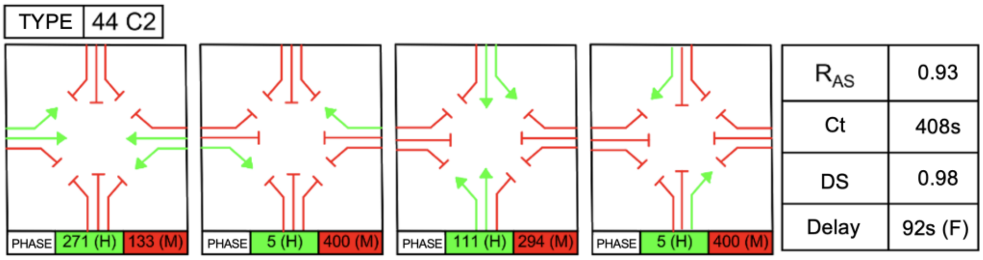

Figure 3. Signal phase analysis result of signalized 44C2 intersection

3.6. Analysis of Signalized Intersection Arrangements (Widening) – Scenario 3

The next step is by increasing the width of the approach for the left turn lane by at least 2 meters. This is in accordance with the 2023 PKJI, which states that with the left turn lane width ≥ 2 m or the left turn is an exclusive lane (LTOR), can reduce the high traffic load. In this condition the right turn vehicles queue during the red signal while the left turn vehicles can directly precede.

The next analysis is to compare the improvement of the '44C2 intersection with widening only' (44C2 Wide) or 'implement a separated direct left turn' (44C2 LTOR). The signal phase and the results of the analysis of the 44C2 Widening and LTOR intersection are shown in **Figure 4**.

The results show that the 44C2 LTOR scenario is better in reducing delays which has a service level of C. This shows that widening the approach for the LTOR lane by at least 2 meters increases the performance of the intersection. Therefore, further analysis will use the 44C2 LTOR scenario to obtain the desired level of service.

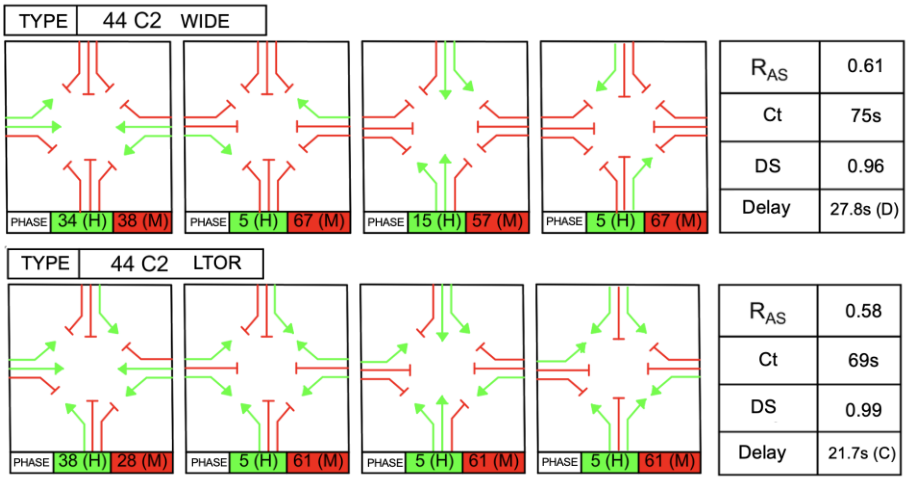

Figure 4. Signal phase analysis results of the 44C2 Widening and LTOR intersection

3.7. Analysis of Signalized Intersection Regulation (LTOR) – Scenario 4

A further analysis of the signalized intersection using the widening route, based on the 44C2 LTOR scheme, is carried out by adjusting the cycle time of each phase to achieve service level B based on the DS or delay (T). The first analysis (44C2 LTOR – 1) is changing the cycle time by using the green time (GT) reference calculation per phase and with the provision that green time phases 2, 3 and 4 are at least 5 seconds. The second analysis (44C2 LTOR – 2) design GT phases 2,3 and 4 are at least 5 seconds and GT phase 1 can be adjusted to obtain intersection delays <15 seconds/PCU or service level B. The third analysis (44C2 LTOR – 3) with the provision that GT phases 2,3 and 4 are at least 5 seconds and GT phase 1 can be adjusted to obtain a DS between 0.61–0.70 and intersection delays <15 seconds/PCU or service level B. The fourth analysis (44C2 LTOR – 4) with the provision that GT phases 2,3 and 4 are at least 10 seconds and GT phase 1 can be adjusted to obtain a DS between 0.61–

0.70 and intersection delays <15 seconds/PCU or service level B. Signal phase, intersection geometry, and analysis results 44C2 LTOR intersection engineering schemes 1–4 are shown in **Figure 5.**

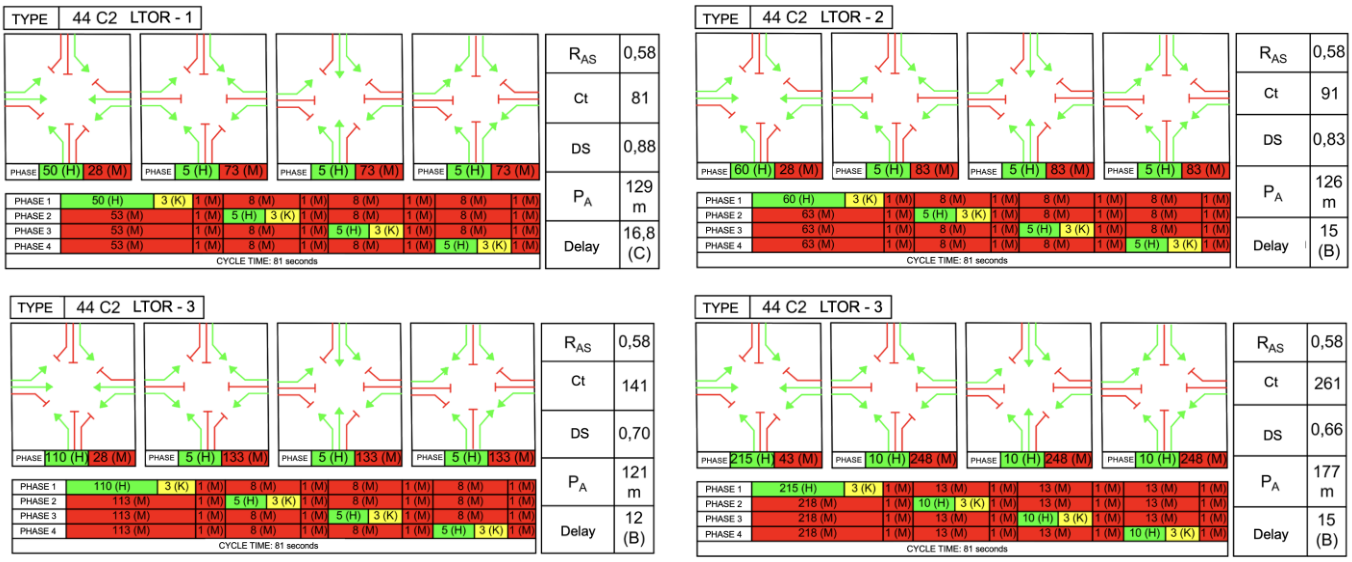

Figure 5. Signal phase analysis results of the 44C2 LTOR intersection schemes 1, 2, 3 and 4

Based on the analysis results of all existing scenarios, increasing the approach width by at least 2 meters increases LOS and capacity, especially on approach roads A (West) and C (East). In scenario 1, the optimal scheme is the second widening scheme, which changes the major approach to 12 meters and the minor to 10 meters, which increases the intersection service to LOS B based on delays. In scenario 2, no widening is carried out, with the optimal scheme being the signalized 44C2 scheme with a R_{AS} of 0.93 and LOS F, which is further analyzed in the advanced scenario. In scenario 3, the optimal scheme is the signalized 44C2 – LTOR scheme with a R_{AS} of 0.58 and LOS C, which is already close to the target LOS B. In scenario 4, the most optimal scheme is the 3rd scheme with LOS B, where the difference is that the 3rd scheme is set to a minimum green time of 5 seconds. For another option, scheme 44C2 LTOR – 2, has also been optimal because it has achieved the LOS B target with a delay of 15 seconds, DJ of 0.83, which is below 0.85, with a shorter cycle time than schemes 3 and 4, which is 91 seconds.

3.8. Yellow Box Junction, Road Markings, and Traffic Signs

At any signalized intersection scheme, it is recommended to use yellow box junction to eliminate the potential jammed traffic queues. The yellow box design can be implemented along with the lane direction, zebra cross, and vehicle stop point markings, following Indonesian national standard based on the Ministry Regulation number 13 and 34 of 2014 [14], [15].

It is recommended to accommodate the use of 4-phase traffic light was to accommodate the complex traffic movement patterns, especially when compared to 3 phases which have the potential to trigger right-turn conflicts. The installation of traffic signs around the intersection is also an important to provide information and warnings to road users. With the implementation yellow box junction, clear road markings, road signs and the improvement to a signalized intersection, it is expected that the performance of the area will increase significantly, reduce delay levels, reduce traffic conflicts, and improve the safety of road users.

4. Conclusion

Based on the analysis and improvement of the performance of the four-leg unsignalized intersection in the Duta Berlian intersection case study, it is known that the peak traffic volume of 3,949.6 PCU/hour has exceeded the intersection capacity of 3,668.5 PCU/hour with a DS of 1.08, an average delay of 23.3 seconds/PCU, and a queuing opportunity of 93%, which indicates poor performance with *a Level of Service* (LOS) C according to PKJI 2023 and Ministry Regulation No. 96 of 2015. This condition is caused by high side frictions, the absence of traffic light, and narrow approaching lane width, especially in minor lanes, exacerbated by illegal parking and commercial activities. Four improvement scenarios were modeled, ranging from approach widening to conversion to a signalized intersection with various phase configurations, where the combination of approach widening, traffic light installation, right turn separation and a dedicated left turn lane on red (LTOR) proved to be the most effective in reducing DS from 1.08 to 0.70 (−35.2%), reducing delays by 48.5%, and increasing LOS to B. All improvement schemes are recommended to be equipped with yellow box junctions and adequate traffic markings and signs. For future research and improvement, it is recommended to conduct driver behavior analysis, microscopic simulations, post-implementation evaluations, additional local accident data, socio-economic impact analysis for non-motorized road users, cost-benefit analysis, synchronization of physical plans with the local regulation. As a long-term solution, studies on the construction of interchange (grade separated junction) such as flyovers or underpasses also need to be considered and analyzed using a more detailed technical and feasibility approach.

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