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Performance Analysis of Unsignalized Intersections Based on PKJI 2023 (Case Study: Imam Bonjol – Taman – Waru Road, Sidoarjo)

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A B S T R A C T

The growth of population and motorized vehicles in Sidoarjo Regency has led to an increase in traffic volume, which impacts the performance of intersections, particularly unsignalized intersections. This study aims to analyze the performance of the unsignalized intersection at Jalan Imam Bonjol – Taman – Waru based on the Indonesian Highway Capacity Manual (PKJI) 2023 and to propose improvement strategies. The research method involves field surveys using manual traffic counting conducted over three days during peak hours, including data on traffic volume, intersection geometry, and vehicle characteristics. The analysis covers traffic volume, intersection capacity, and degree of saturation (DS). The results show that the existing condition has a DS value of 0.86 with an average delay of 14.71 seconds/pcu, indicating that the intersection is operating under saturated conditions and does not meet the acceptable standard (DS < 0.85). Therefore, an improvement strategy is proposed by converting the intersection into a signalized intersection with a three-phase system. The results indicate a significant improvement, with the DS decreasing to 0.61, resulting in a more stable, efficient, and controlled traffic condition. Thus, the implementation of traffic signals is recommended to improve performance, traffic flow, and safety at the study location.

Contribution to Sustainable Development Goals (SDGs):
SDG 3: Good Health and Well-being:
SDG 9: Industry, Innovation, and Infrastructure:
SDG 11: Sustainable Cities and Communities
SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

The increase in population and motorized vehicles in Indonesia, particularly in urban areas, has triggered various transportation problems, such as congestion, traffic delays, and declining road safety. One area experiencing these conditions is Sidoarjo Regency in East Java Province. Based on data from the Sidoarjo Regency in Figures 2024 published by the Central Statistics Agency (BPS), Sidoarjo's population in 2023 reached 1,980,000, making it one of the East Java Province is a densely populated region. This situation has led to increased traffic volume, particularly in strategic corridors connecting residential areas, industrial areas, and economic centers [1]. The increasing number of vehicles and the mobility of people, goods, and services require adequate infrastructure. This requires not only additional transportation facilities but also the development of effective infrastructure to regulate and control traffic flow [2]. The increase in vehicle numbers without corresponding infrastructure development will lead to traffic conflicts, particularly at intersections [3].

An intersection is a point where several road sections meet and plays a crucial role in the transportation system, potentially causing conflict between traffic flows from various directions [4].

Unsignalized intersections are part of the transportation network without traffic lights. Road users crossing these intersections are required to exercise increased caution before continuing their journey, paying attention to traffic conditions in both directions to ensure safety [5]. One location facing traffic problems is the unsignalized intersection on Jalan Imam Bonjol–Taman–Waru. This intersection plays a crucial role in serving vehicle movement, but is not equipped with traffic control, so its regulation depends on road priorities and user behavior. This condition often results in irregular traffic flow, high delays, and potential conflicts between vehicles, especially during rush hour [6]. High traffic density at unsignalized intersections can lead to increased levels of saturation and the risk of accidents. Therefore, an intersection performance analysis is needed, encompassing geometric aspects, traffic volume, capacity, and vehicle movement patterns, to assess its effectiveness in serving traffic flow [7].

1.2. Literature Review

1.2.1. Intersection

Road intersections are points where traffic flows meet, potentially leading to conflicts between vehicles. Intersection types include signalized and unsignalized intersections, which are determined based on environmental characteristics, traffic volume, and geometric conditions to ensure smooth and safe flow. Therefore, intersection planning requires comprehensive technical and environmental analysis [8].

1.2.2. Unsignalized Intersections

An unsignalized intersection is an intersection in the transportation network that lacks traffic lights. Road users passing through it are required to exercise increased caution by observing traffic conditions in both directions before proceeding to ensure safety [5].

1.2.3. Geometric Data

Intersection geometry is the physical arrangement of road elements at the meeting point of two or more sections that affect vehicle movement when entering, exiting, and turning in a limited conflict area, including lane width, number of approach lanes, intersection angle, curve radius, median, turning channel, markings, and pedestrian arrangement [9]

1.2.4. Traffic Flow Data

Traffic flow data includes vehicle volume (vehicles/hour), traffic composition, and planned hour flow (QJP). Vehicle composition is used to calculate the passenger car unit factor (PCU), while QJP is obtained by multiplying LHRT by the K factor. In addition, calculations are made for the total intersection flow, turning flow (left and right), and straight current to determine the turning ratio and minor road current ratio.

1.2.5. The intersection capacity (C)

The intersection capacity (C) is calculated from the total flow entering all intersection arms and is the result of multiplying the basic capacity (C_0) by a correction factor that takes into account actual conditions compared to ideal conditions [10]. Capacity of an unsignalized intersection is determined based on the intersection type and approach width. Intersection types are classified by the number of arms and the number of lanes on major and minor roads. The basic capacity (C_0) is obtained from ideal conditions and then adjusted to field conditions using a correction factor.

Capacity adjustments take into account several factors, namely approach width (FLP), median presence (FM), city size (FUK), side obstacles (FHS), and traffic flow characteristics such as left turn ratio (FBKi), right turn ratio (FBKa), and minor road flow ratio (FRmi). The final intersection capacity is obtained by multiplying the base capacity by all of these correction factors. The capacity of an unsignalized intersection can be calculated using the following equation.

$$C = C_0 \times F_{\text{LP}} \times F_{\text{M}} \times F_{\text{UK}} \times F_{\text{HS}} \times F_{\text{BKi}} \times F_{\text{BKa}} \times F_{\text{Rmi}}$$

Information:

C : Capacity of unsignalized intersection (SMP/hour).
C_0 : Capacity of unsignalized intersection (SMP/hour).
F_{LP} : Average approach width correction factor.
F_M : Median type correction factor.
F_{UK} : City size correction factor.
F_{HS} : Side resistance correction factor.
F_{BKi} : Left turn current ratio correction factor.
F_{Bki} : Right turn current ratio correction factor.
F_{Rmi} : Current ratio correction factor of minor

1.2.6. Degree of saturation (DS)

The degree of saturation is the ratio between the intersection capacity (C) and the total traffic flow (q_{TOT}) [11]. The degree of saturation at an unsignalized intersection can be calculated using the following equation.

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

Information :

D_S : Degree of Saturation.
C : Capacity of unsignalized intersection arm (SMP/hour).
Q : Traffic volume (SMP/hour).

1.2.7. Delay

Delays at intersections consist of traffic delays (TLL) due to interactions between vehicles and geometric delays (TG) caused by vehicle maneuvers such as stopping or turning at intersections [12].

1.2.8. Queue Opportunity

The queue probability (PA) is expressed as a percentage as a range of possibilities determined based on the degree of saturation (DS) value [13]. The PA value consists of an upper and lower limit calculated using a specific equation. Furthermore, the queue probability can also be obtained through a graph of the relationship between PA and DJ, where the graph area indicates the range of possibilities, while the boundary lines depict the minimum and maximum values of the queue probability

1.3. Research Objective

This study aims to evaluate the performance of unsignalized intersections on Jalan Imam Bonjol–Taman Waru, Sidoarjo by referring to the 2023 Indonesian Road Capacity Guidelines (PKJI). The results of this evaluation are expected to provide an overview of existing conditions, identify key problems, and generate recommendations to improve traffic flow, efficiency, and safety at the research location

2. MATERIALS AND METHODS

2.1. Research Location

The research location was chosen because it connects residential, commercial, and industrial areas with high traffic activity. This condition causes increased traffic volume and delays at unsignalized intersections, making it a suitable object for performance evaluation. Taman– Waru Sidoarjo is shown in Figure 1.

Fig. 1. Unsignalized Intersection Location

2.2. Presentation of Survey Data

The survey was conducted over three days, at three time periods (morning, afternoon, evening) with 15-minute intervals. Data were collected through manual enumeration, including traffic volume, vehicle classification (motorcycles, light vehicles, heavy vehicles), direction of travel, and intersection geometric conditions

2.3. Presentation of Survey Data

Data collection in this study is divided into two, namely:

a. Primary Data
   Primary data were obtained through direct observation on site, including traffic volume, approach width, number of lanes, and vehicle classification. Traffic volume was collected through manual enumeration or video recording during morning, afternoon, and evening rush hours for three days, then classified into motorcycles, light vehicles, and heavy vehicles for analysis purposes in passenger car units (SMP). Geometric data, such as approach width and number of lanes, were used as the basis for capacity calculations and intersection performance evaluation.
b. Secondary data
   Secondary data was obtained from related agencies and supporting sources, including LHR data and location maps to support the identification of field conditions.

2.4. Data Processing Analysis

Data analysis and processing in this study were carried out with reference to the 2023 Indonesian Road Capacity Guidelines (PKJI) with the following stages:

a. Traffic volume analysis is carried out by calculating the number of vehicles surveyed based on time intervals to obtain the hourly volume.
b. Intersection capacity analysis is calculated from the basic capacity adjusted for factors such as approach width, side obstacles, city size, and turning and minor road flows.
c. Analysis of the degree of saturation (DJ) is carried out by comparing traffic volume (Q) to capacity (C) to assess the level of service and performance of the intersection.

3. RESULT AND DISCUSSION

3.1. Traffic Flow Volume Data

The unsignalized intersection on Jalan Imam Bonjol Taman–Waru is a crucial part of the traffic network, with a high volume of traffic. Therefore, a performance analysis is required to assess current operational conditions and identify any traffic issues. This analysis includes capacity, saturation level, and intersection delays. Based on the results of a traffic volume survey, the highest vehicle flow occurred on Monday, March 17, 2025, between 7:00 and 8:00 a.m., as presented in Table 1 below:

Table 1. Highest Traffic Volume Survey Data at the Unsignalized Intersection of Imam Bonjol – Taman – Waru Road

Type	Busiest Time Monday	Vehicle/hour									Total (Vehicle/hour)
		Imam Bonjol Street (S)			Road Taman (B)			Road Waru (T)			
		Ki	Ka	Lrs	Ka	Ki	Lrs	Ka	Ki	Lrs	
SM	07:00 -07:15	79	60	0	0	109	177	140	0	164	4335
	07:15 -07:30	40	50	0	0	115	180	138	0	158	
	07:30 - 07:45	41	55	0	0	105	174	134	0	146	
	07:45 - 08:00	70	57	0	0	108	179	137	0	135	
MP	07:00 -07:15	33	28	0	0	63	73	58	0	83	
	07:15 -07:30	40	25	0	0	49	78	53	0	69	
	07:30 - 07:45	37	22	0	0	53	60	47	0	77	
	07:45 - 08:00	27	19	0	0	40	65	44	0	63	
KB	07:00 -07:15	7	9	0	0	27	25	20	0	30	
	07:15 -07:30	3	6	0	0	22	20	23	0	28	
	07:30 - 07:45	5	4	0	0	17	18	18	0	26	
	07:45 - 08:00	2	3	0	0	13	14	15	0	23	

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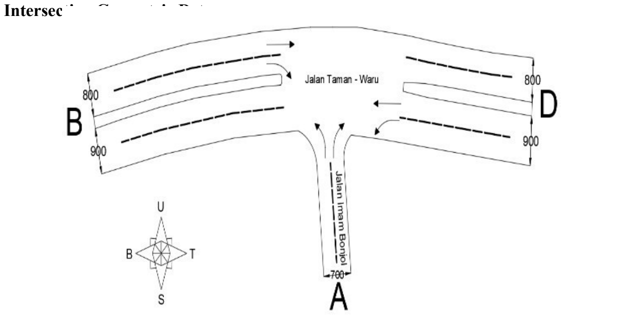
3.2. Geometric Data and Traffic Flow Data of Unsignalized Intersections

At the unsignalized intersection of Jalan Imam Bonjol–Taman–Waru, the approach widths are 9 m on the East approach (major), 8 m on the West approach (major), and 3.5 m on the South approach (minor). This intersection is located in a commercial neighborhood with intersection type 324 (three arms, two directions, four lanes) and equipped with a median on the major road with a width of 1.5 meters. Traffic flow data was obtained from the results of a three-day survey, namely Monday, Friday, and Saturday, which was conducted at 06.00–09.00, 11.00–14.00, and 15.00–18.00 with a recording interval of every 15 minutes. Based on the survey results, peak traffic flow occurs on Monday at 07.00–08.00. The results of the survey of existing geometric conditions and traffic flow calculations at the unsignalized intersection of Jalan Imam Bonjol–Taman–Waru, which includes lane configuration and direction of vehicle movement, are presented in Table 2 below:

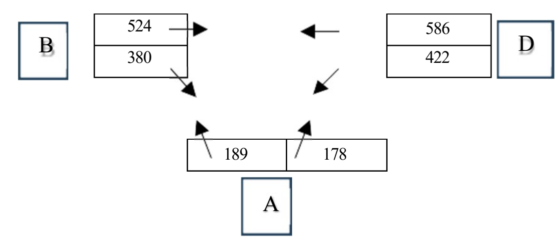
Table 2. Result of the survey of existing geometric conditions and data from traffic flow calculations at the unsignalized intersection of Jalan Imam Bonjol – Taman – Waru

INTERSECTION	Date : 22 March 2025	Signed by : Lisa Vatma
	City : Sidoarjo	Province : East Java
INPUT DATA	Major Road : Highway Taman - Waru (B-D)	
GEOMETRIC DATA	Minor Road : Road Imam Bonjol (A)	
TRAFFIC FLOW DATA	Period : 07.00 - 08.00	

Intersec



Traffic Flow Data



Median on Main Road				Wide	~~Narrow~~						
Traffic Composition (%):		MP		SM=		KB=		Factor skr=		Factor k=	
Factor SMP		MP, EMP = 1,0		SM, EMP = 0,2		KB, EMP = 1,8		qKB Total			qKTB
Traffic Flow		Vehicle/hour	SMP/Hour	Vehicle/hour	SMP/Hour	Vehicle/hour	SMP/Hour	Vehicle/hour	SMP/Hour	RB	Vehicle/hour
Minor Road From Approach A	qBKI	137	137	230	46	17	31	384	214	0.55	46
	qLRS	0	0	0	0	0	0	0	0		0
	qBKa	94	94	222	44	22	40	338	178	0.45	44
	qTotal	231	231	452	90	39	71	722	392		90
Total jalan minor, qmi		231	231	452	90	39	71	722	392		90
Major Road From Approach B	qBKI	0	0	0	0	0	0	0	0	0.00	0
	qLRS	276	276	710	142	77	139	1063	557		54
	qBKa	205	205	437	87	79	142	721	434	0.44	47
	qTotal	481	481	1147	229	156	281	1784	991		101
Major Road From Approach D	qBKI	202	202	549	110	76	137	827	449	0.43	43
	qLRS	292	292	603	121	107	193	1002	606		59
	qBKa	0	0	0	0	0	0	0	0	0.00	0
	qTotal	494	494	1152	231	183	330	1829	1055		102
Total Major Roads, qma		975	975	2299	460	339	611	3613	2046		203
Total Of Minor Roads And Major Roads	qT,Bki	339	339	779	156	93	168	1211	663	0.27	89
	qT,LRS	568	568	1313	263	184	332	2065	1163		113
	qT,Bka	299	299	659	131	101	182	1059	612	0.25	91
qTOT = qmi + qma =		1206	1206	2751	550	378	682	4335	2438	0.52	293
									Rmi = qmi / qTOT=		0.1608
									RKTB=qKTB/qKB=		0.0676

3.3. Calculation of Unsignalized Intersection Performance

3.3.1. Approach Width and Intersection Type

The width of the approach to major and minor roads is determined based on the results of field observations through measurements

Direct traffic flow and analysis of factors influencing road geometry. Intersection type indicates the number of arms (meeting sections) and the number of lanes on major and minor roads. Approach width is the width of the road approaching the intersection area [10]. The results of the calculation of approach width and intersection type are shown in Table 3 below:

Table 3. Calculation Results of Approach Width and Type

Approach Width and Intersection Type										
Choice	Number of Intersection Arms	Approach Width (m)						LRP	Number of Lanes		Intersection Type
		Minor Street			Mayor Street				Minor Street	Mayor Street	
		LA	LC	LAC	LB	LD	LBD				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
MONDAY	3	3.50	0.00	3.50	8.00	9.00	8.50	6.00	2	4	324

3.3.2. *Intersection Capacity (C)*

Capacity calculations show that the basic capacity of the intersection (C_0) is 3200 SMP/hour. Next, adjustments are made with several correction factors, namely the approach width correction factor (FLP) is 1.01, the median correction factor on major roads (FM) is 1.05, the city size correction factor (FUK) is 1, the side resistance correction factor (FHS) recorded 0.70, left turn correction factor (FBKi) is 1.275, the right turn correction factor (FBKa) is 0.86, and the minor/total ratio correction factor (FRMi) is 1.094. Thus, the intersection capacity (C) can be calculated as follows:

$C = C_0 \times F_{LP} \times F_M \times F_{UK} \times F_{HS} \times F_{BKi} \times F_{BKa} \times F_{Rmi}$

$C = 3200 \times 1{,}01 \times 1{,}05 \times 1{,}00 \times 0{,}70 \times 1{,}275 \times 0{,}86 \times 1{,}094$

C = 2850 SMP/hour

3.3.3. *Degree of Saturation (Ds)*

The degree of saturation is the ratio between the intersection capacity (C) and the total traffic flow (qTOT). Based on the calculation results, the intersection capacity is 2850 SMP/hour and the total traffic flow is 2438 SMP/hour, so that:

$$Ds = \frac{qTOT}{C} = \frac{2438}{2850} = 0{,}86$$

The degree of saturation value of 0.86 indicates that the intersection conditions have slightly exceeded the recommended limits. in PKJI 2023, namely ≤ 0.85.This indicates that the intersection performance is starting to become less than optimal, with traffic flow approaching maximum capacity and potentially causing delays and queues of vehicles.

3.3.4. *Intersection Delay (T)*

Intersection delay (T) is the additional time vehicles experience due to traffic interactions at the intersection, consisting of traffic delay (TLL) and geometric delay (TG). Based on the calculation results, the traffic delay is obtained ((TLL) of 10.63 seconds/SMP and geometric delay (TG) of 4.08 seconds/ SMP, so the total delay at the intersection is:

$T = T_{LL} + T_G$

T = 10,63 + 4,08

T = 14,71 sec/SMP

In addition, traffic delays on each approach show quite significant differences, namely delays on major roads (T LLMa)of 7.78 seconds/SMP, while on minor roads (TLLMi) of 25.51 seconds/junior high school. These delay values indicate that vehicles on minor roads experience greater obstacles than those on major roads. Overall, the intersection delay of 14.71 seconds/smp indicates that intersection performance is beginning to decline, influenced by high traffic flow and the intersection's near-saturation condition.

3.3.5. *Queue opportunity (P_A)*

Queue opportunity (P_A) is an indicator that shows the possibility of vehicle queues at an intersection due to traffic flow interactions. Based on the calculation results with a degree value (Ds) of 0.86, the probability of queues is obtained with an upper limit of 29.71% and a lower limit of 58.7%.

This range of values indicates a significant likelihood of vehicle queues at the intersection, especially during heavy traffic conditions. The higher the saturation level, the greater the likelihood of queues. Therefore, this condition confirms that the intersection's performance is beginning to suboptimal and has the potential to cause traffic congestion, particularly during peak hours.

3.4. *Handling of Unsignalized Intersections*

The performance of the unsignalized intersection of Jalan Imam Bonjol Taman–Waru in its existing condition shows a degree of saturation (DS). of 0.86, indicating that traffic flow has approached or even exceeded the intersection's capacity and has not yet met the 2023 PKJI criteria (DJ < 0.85). This condition indicates the need for mitigation efforts to improve intersection performance. One alternative that can be implemented is the installation of three-phase traffic signals to more effectively regulate vehicle movement. The calculation for intersection management with the implementation of three-phase signals is as follows.

a. Intersection Geometry Data

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Table 4. Geometric Data of Imam Bonjol – Taman – Waru Intersection with the Addition of 3 Signal Phases

Approach Code (U,S,T,B)	Road Environment Type (KIM, KOM, AT)	Obstacle Class Samping (High/Low)	Median (Yes/No)	Approach Slope +/- (%)	BKIJT Turn Left, Continue (Yes/No)	Distance to First Parked Vehicle (m)	Approach Width (m)			
							At the Stop Line LM (m)	At the Stop Line LM (m)	On the Left Turn Lane of BKIJT (m)	In Exit Lane LK(m)
S	KOM	T	T	0	T	0	3.50	3.50	0	0.00
B	KOM	T	Y	0	T	0	8.00	8	0	9.00
T	KOM	T	Y	0	Y	0	9.00	6	3	8

b. Calculation of Passenger Car Equivalents at Intersections

Table 5. EMP Calculation Results at the Imam Bonjol – Taman – Waru Intersection with the Addition of 3 Signal Phases

Approach Code	Direction	Motor vehicle											
		Passenger Car (MP)			Passenger Car (MP)			Motorcycle (SM)			Total Motorized Vehicles		
		Vehicle/hour	smp/ hour		Vehicle/hour	smp/ hour		Vehicle/hour	smp/ hour		Vehicle/hour	smp/ hour	
			Protected	Challenged		Protected	Challenged		Protected	Challenged		Protected	Challenged
U	Bki / Bkijt	137	137	137	17	22	22	230	35	92	384	194	251
	Straight	0	0	0	0	0	0	0	0	0	0	0	0
	Bka	94	94	94	22	29	29	222	33	89	338	156	212
	Total	231	231	231	39	51	51	452	68	181	722	350	463
B	Bki / Bkijt	0	0	0	0	0	0	0	0	0	0	0	0
	Straight	276	276	276	77	100	100	710	107	284	1063	483	660
	Bka	205	205	205	79	103	103	437	66	175	721	374	483
	Total	481	481	481	156	203	203	1147	173	459	1784	857	1143
T	Bki / Bkijt	202	202	202	76	99	99	549	82	220	827	383	521
	Straight	292	292	292	107	139	139	603	90	241	1002	521	672
	Bka	0	0	0	0	0	0	0	0	0	0	0	0
	Total	494	494	494	183	238	238	1152	172	461	1829	904	1193

c. Intersection Capacity

Table 6. Capacity Calculation Results of Imam Bonjol – Taman – Waru Intersection with the Addition of 3 Signal Phases

Approach Code	the phase	Approach type	Saturated Current SMP/Hour	Traffic Flow SMP/Hour	Flow Ratio	Phase Ratio	Green Time second	Capacity SMP/Hour
S	1	P	2100	156	0,1041	0,1876	17,07	256
B	2	P	4800	857	0,2291	0,4128	37,56	1405
T	3	P	3600	521	0,2218	0,3996	36,37	854

d. Degree of Saturation

Table 7. Calculation Results of the Imam Bonjol – Taman – Waru Intersection with the Addition of 3 Signal Phases

Approach Code	Degree of Saturation	Nq	Queue Length m	Vehicle Stop Ratio	Number of Stopped Vehicles SMP/Hour	Traffic Delays dec/SMP	Geometric Delay dec/SMP	Total Delay dec/SMP
S	0.61	4.29	25	0.891	139	42.32	4.22	7260
B	0.61	19.56	49	0.739	633	26.0	3.6	25401
T	0.61	12.11	40	0.753	392	27.2	3.6	16068

From the analysis calculation of handling the Imam Bonjol – Taman – Waru intersection with the provision of 3 signal phases, it resulted in a degree of saturation (Dj) of 0.61 on each arm. This can be concluded that this treatment is declared efficient in improving the unsignalized intersection of Imam Bonjol – Taman – Waru. The calculation of the average delay at the Imam Bonjol – Taman – Waru intersection with the addition of 3 signal phases is as follows:

$$\text{Average intersection delay} = \frac{\text{Total number of delay}}{\text{Amount of traffic flow}}$$

$$\text{Average intersection delay} = \frac{7260 + 25401 + 16068}{156 + 857 + 521}$$

$$\text{Average intersection delay} = 31{,}77 \text{ sec/SMP}$$

4. CONCLUSION

Based on the results of the existing condition performance analysis, the unsignalized intersection of Jalan Imam Bonjol–Taman–Waru has a degree of saturation (DJ) of 0.86 and an average delay of 14.71 seconds/SMP. The DJ value has exceeded the recommended limit (DJ < 0.85), indicating that the traffic flow is in a saturated condition and approaching or exceeding capacity. This condition has the potential to cause congestion due to the high volume of vehicles. Therefore, handling efforts are needed to reduce the degree of saturation and delay values so that the intersection performance becomes more optimal and improves traffic flow and safety.

Based on the results of the existing condition performance evaluation, the management strategy for the unsignalized intersection on Jalan Imam Bonjol–Taman–Waru is implemented by changing the regulation system to a three-phase signalized intersection. The implementation of this signal aims to reduce conflicts over previously uncontrolled vehicle movements. Analysis results showed a significant performance improvement, marked by a decrease in the degree of saturation (DJ) from 0.86 to 0.61. This value is below the recommended limit (DJ < 0.85), so that the operational conditions of the intersection are more stable, controlled, and efficient, and are able to improve the level of service and traffic safety.

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