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Design of Coordination Between Signalized Intersections (A Case Study in Gayamsari and Lamper Intersections)

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Abstract

Gayamsari Intersection and Lamper Intersection in Semarang City are signalized intersections that experience high levels of vehicle queues and delays, especially during peak hours. This study aims to design signal coordination between intersections to improve traffic performance. The analysis was conducted based on the Indonesian Road Capacity Guidelines (PKJI) 2023, with a five-day field survey covering active days (Monday-Wednesday) and weekends (Saturday-Sunday). Peak hour traffic volume data was used to analyze existing conditions, including degree of saturation (DJ), queue length (PA), and delay (T) parameters. Several signal cycle planning scenarios were tested, and an optimal cycle of 180 seconds for weekdays and 130 seconds for weekends was obtained. Signal coordination can only be applied from Lamper to Gayamsari intersection, because in the reverse direction straight vehicles at Gayamsari intersection do not face red signals. Signal coordination is designed using the bandwidth and offset time method, with an offset of 45 seconds. The design results show a bandwidth of 60 seconds (morning) and 81 seconds (afternoon) on active days, and 43 seconds (morning) and 51 seconds (afternoon) on weekends. This design is expected to reduce vehicle delays and queues, and improve traffic efficiency at both intersections.

Introduction

Urban transportation problems, especially traffic, are part of everyday human life. The higher the human activity in an area, the higher the level of mobility. This activity is caused by the existence of attraction areas and generation areas that increase traffic demand (Murtiyoso & Subagyo, 2021; Zihansyah et al., 2022). The road network is one of the elements of a transportation network in an area as a supporting infrastructure for traffic activities. However, the road network has a limited capacity to accommodate all passing traffic. The increase in traffic infrastructure is not proportional to the increase in traffic in an area (Fauziah et al., 2016; Tara et al., 2024; Kozerska, 2021; Olsen et al., 2016; Zhang et al., 2021).

If the increase in traffic demand is not followed by an adequate increase in traffic infrastructure, it will create an unbalanced situation in traffic such as congestion (Ari, 2022; Munandar et al., 2023; Subair et al., 2024; Lieberthal et al., 2024; Zhao et al., 2022; Morandi, 2021). Congestion has become a major problem in all major cities in Indonesia. The construction of new roads is no longer an effective solution to overcome congestion because land in urban areas is already dense and limited (Kirono et al., 2018; Nurcahyanto, 2021; Taillanter & Barthelemy, 2023; Glaeser, 2022). The most vulnerable point on the road network is the intersection point, where the road network intersects, causing conflicts in traffic

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movement (Kushari, 2020; Patrias & Lulie, 2021; Wang et al., 2022). Therefore, at the intersection point must have a system in regulating or providing maximum service so that traffic activities run smoothly and safely by using Traffic Signal Devices (APILL) (Agrahari et al., 2024; Vieira et al., 2024).

Traffic light systems are a way to manage traffic at intersections that can also increase the capacity of the intersection to serve traffic flow, reduce accidents, and delay (T) (Gulo, 2019; Putra et al., 2022; Radivojević et al., 2021; Elsagheer Mohamed & AlShalfan, 2021). What can be done in facilitating movement at intersections is to minimize the occurrence of traffic flow conflicts. The problem at the intersection point is the improper arrangement of traffic signal lights that disrupt the smooth flow of traffic as a result of queuing or accumulation on each arm of the road (Fedoravie, 2017; Zebua, 2021; Vieira et al., 2024; Marini et al., 2025;). Analysis of the intersection is needed to determine the performance of the intersection in order to always update strategies to optimize an urban road network. As we understand that, urban road networks are road networks that have a fairly high level of movement (Maulana & Nugraha, 2019; Sonia, 2022; Chen et al., 2021; Hosseinian & Mirzahossein, 2024; Tomar et al., 2022; Mohamed & Radwan, 2022).

Lamper intersection, which is directly connected to Gayamsari intersection with a distance of about 500 meters, has the same level of density, is in a commercial area and is one of the access doors to the Great Mosque of Central Java and is a meeting point for 4 arms. This makes the Lamper intersection an intersection that has a fairly high level of busyness, there are also often long queues at peak hours. Seeing the length of the queue at the intersection, a temporary conclusion can be drawn that the Lamper intersection has reached a high level of saturation and is suspected to no longer meet the applicable terms and conditions according to the standard level of service of a good intersection. However, it is still necessary to conduct a scientific analysis to draw the correct conclusions in accordance with those contained in the Indonesian Road Capacity Guidelines (PKJI) 2023 and / or in the Minister of Transportation Regulation (Permenhub) No. 96 of 2015.

In the Minister of Transportation Regulation No. 96 of 2015, it is explained that the level of service of an intersection is classified into 6 levels of service, with the best level of service being level A with a maximum vehicle delay of 5 seconds and the worst level of service being level F with a vehicle delay of more than 60 seconds. Based on the standardization of intersection services and looking at the current existing conditions, the Gayamsari and Lamper intersections have not met the best level of service expected. Where the minimum level of service of the expected intersection on the primary arterial road is level of service B, the vehicle delay time is 5.1 - 15 seconds. In addition, the land use area at the Gayamsari and Lamper intersection is in a commercial and public service area, there are many shops, offices, shopping centers and hospitals and restaurants and others. This can be a trip pull and generation that can increase the movement at the intersection, thus increasing the degree of saturation, queue length and longer vehicle delay time at the intersection. Thus it is necessary to conduct an in-depth study and signaling engineering at the Gayamsari and Lamper intersections in order to meet the expected service standards and other criteria in the Indonesian Road Capacity Guidelines (PKJI) 2023.

This study aims to analyze the existing performance of two signalized intersections located on congested corridors in Semarang City, namely Gayamsari intersection and Lamper intersection, and design an optimal signal coordination system between them to improve traffic efficiency. Intersection performance was analyzed based on the parameters of degree of saturation (D_J), queue length (P_A), and delay (T), according to PKJI guidelines (2023). After obtaining a description of the actual conditions, this study aims to determine the most effective signal cycle time and design one-way signal coordination using the bandwidth and offset time methods to produce a signal pattern capable of forming a green wave. With this

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coordination, it is expected that vehicle queues and delays can be minimized, travel time becomes more efficient, and the level of service of the intersection increases in accordance with the standards set.

Methods

This research was conducted using a quantitative approach through a case study of two signalized intersections in Semarang City, namely Gayamsari intersection and Lamper intersection. This method was chosen to analyze the existing traffic performance and design a signal coordination system between intersections based on technical parameters in accordance with the Indonesian Road Capacity Guidelines (PKJI) 2023 and Minister of Transportation Regulation No. 96 of 2015.

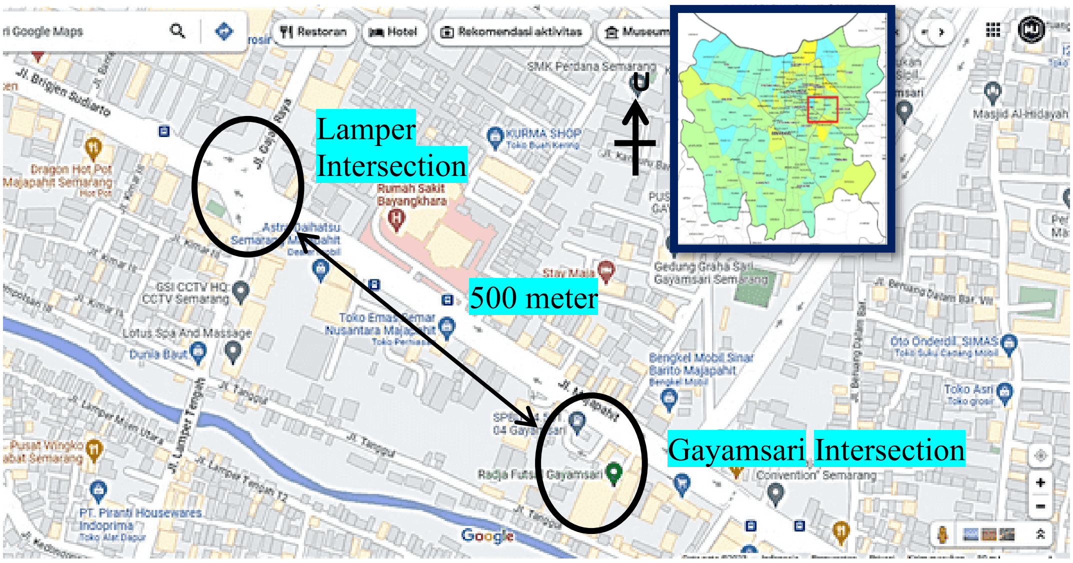

Figure 1. Research Location

The primary data required for the analysis of signalized intersections are traffic flow data, signaling, and intersection geometrics at Gayamsari intersection and Lamper intersection, which are described in detail as follows: a) Traffic flow data, in the form of traffic flow released during the green light on each arm of the road; b) Queue length data, in the form of vehicle queue length data reviewed at each intersection. Measurements are made when the signal shows the light at the end of green to the end of red with the help of a roll meter, a white marker to facilitate measurement; c) Signal and phase cycle time data, in the form of the total time of the entire arm including green time, yellow time, and red time; d) Intersection geometric data, approach width (L), entry width (LM), exit width (LK), left turn lane width (LBKi), right turn lane width (LBKa), conflict point distance in each arm (Lav and Lev), and slope; d) Observations were made at 06:30 - 08:30 (morning) and 15:30 - 17:30 (afternoon), Saturday - Wednesday, August 24-28, 2024.

Secondary data is obtained through data and information searches made by relevant agencies such as the Semarang City Transportation, Communication and Informatics Office and data available from several official internet sites of the Semarang City Population and Civil Registration Office.

After field observation by recording video at the intersection, the calculation of existing intersection performance according to the Indonesian Road Capacity Guidelines (PKJI) 2023 and the design of signal coordination between intersections using the bandwidth and offset time methods.

An intersection performance analysis is conducted to determine the level of service of the intersection under current traffic conditions. The assessment is based on three main

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parameters, namely degree of saturation (D_J), average delay (T), and queue length (P_A). The analysis method refers to the provisions in PKJI (2023) which is a national standard in the assessment of signalized intersection performance.

Degree of Saturation (D_J) is calculated by dividing the volume of traffic flow by the capacity of the approach. The ideal D_J value is < 0.85. A D_J value > 1 indicates that the vehicle volume exceeds the approach capacity, indicating saturation.

Average Delay (T) is measured in seconds/vehicle and calculated using the formula provided in PKJI (2023), which considers signal timing, red light frequency, and cycle length. The delay represents the efficiency of the intersection service; the lower the value, the better the intersection performance.

Queue Length (P_A) is measured directly in the field using a digital meter during the red phase. Queue length is measured from the stop line to the last stopped vehicle. The P_A value is also an indicator of the intersection's capacity to accommodate vehicles during peak conditions.

After knowing the performance of the existing intersection, the planning stages of the new cycle time and signal coordination between intersections are carried out in the following stages:

Determination of Optimal Cycle Time

This process is carried out by calculating the cycle time based on the Webster method and PKJI cycle calculation (2023), then tested in several alternative scenarios. Each scenario will provide different values of D_J, T, and P_A. The purpose of adjusting cycle time is to minimize total delay and minimize queue length.

Several scenarios were tested for weekdays and weekends. The planning results show that: 1) The best cycle time for weekdays is 180 seconds 2) The best cycle time for weekends is 130 seconds.

Signal Coordination Design

Coordination design is carried out between Lamper (upstream) and Gayamsari (downstream) intersections with bandwidth and offset time methods. The steps are as follows: 1) Offset Time Calculation: Offset is calculated based on the distance between intersections (± 500 meters) and the average speed of vehicle flow (obtained from field surveys). Offset formula = (distance/average speed) × 3600 seconds/hour. The optimal offset was found to be 45 seconds; 2) Bandwidth Calculation: Bandwidth is the width of green time that a vehicle platoon can effectively utilize. The bandwidth is determined through a signal coordination diagram depicting the green wave. The results show that: 1) Weekdays: morning bandwidth = 60 seconds, afternoon = 81 secondsl; 2) Weekends: morning bandwidth = 43 seconds, afternoon = 51 seconds.

Evaluation and Validation

Evaluation was conducted to assess the effectiveness of the new cycle time planning and signal coordination system designed, compared to the existing conditions.

Performance Evaluation: Each scenario was analyzed using D_J, T, and P_A parameters. The plan was considered successful if there was a reduction in all three parameters. Graphs and tables were used to show significant changes in delay and queue length.

Validation of Results: Validation was done by comparing the performance of the existing intersection to the performance after coordination was implemented simulatively. D_J values approaching ≤ 0.85 and delays < 25 seconds on most approaches indicate that the coordination design successfully improved the level of service of the intersection to category B or C, in

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accordance with the minimum standards for arterial roads in Minister of Transportation Regulation No. 96 of 2015.

Results and Discussion

Existing Condition Intersection Performance Analysis

Table 1. Existing Intersection Performance Morning Peak Hour, Tuesday, August 27, 2024

Intersection	Location	J_0	J	q	C	D_J	P_A	T	LOS
Gayamsari	Jl. Exit Tol Gayamsari	5400	4966	975	709	1,37	152,87	213,50	F
	Jl. Majapahit (East-Turn Right)	3600	3696	1180	1848	0,64	113,59	29,88	D
	Jl. Majapahit (West)	4800	4368	1398	1092	1,28	205,22	135,40	F
Lamper	Jl. Gajah Raya	4200	4185	670	677	0,99	109,06	108,70	F
	Jl. Majapahit (Go straight)	6000	5495	2482	2223	1,12	286,94	82,62	F
	Jl. Majapahit (Turn Right)	3600	3551	363	411	0,88	65,87	102,26	F
	Jl. Lamper Tengah	4800	4994	1001	1010	0,99	135,40	94,78	F
	Jl. Brigjend Sudiarto (Go Straight)	3600	3278	1071	1326	0,81	156,71	53,10	E
	Jl. Brigjend Sudiarto (Right)	1800	1783	185	206	0,90	78,43	132,02	F
						1,00	144,90	105,81	F

Analysis of intersection performance under existing conditions based on morning peak hour survey data on Tuesday, August 27, 2024, shows that most of the approaches at the Gayamsari and Lamper intersections experience high levels of saturation and significant delays. The overall average degree of saturation of the Lamper intersection is 1.00 with an average delay of 105.81 seconds, indicating that the intersection already exceeds the optimal capacity. Overall, the existing conditions of both intersections are at a poor level of service and require cycle time re-planning interventions as well as signal coordination design between intersections to reduce traffic saturation and delays.

Table 2. Existing Intersection Performance Afternoon Peak Hour, Tuesday, August 27, 2024

Intersection	Location	J_0	J	q	C	D_J	P_A	T	LOS
Gayamsari	Jl. Exit Tol Gayamsari	5400	4812	1059	830	1,28	150,62	166,52	F
	Jl. Majapahit	3000	3118	771	968	0,80	119,23	54,47	E

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	(East – Turn Right)								
	Jl. Majapahit (West)	5400	4994	1238	2066	1,14	262,87	74,58	F
Lamper	Jl. Gajah Raya	4200	4075	490	479	1,02	88,01	137,12	F
	Jl. Majapahit (Go Straight)	5100	4667	1278	1922	0,67	116,22	44,71	E
	Jl. Majapahit (Turn Right)	2100	2102	272	371	0,73	74,07	77,99	F
	Jl. Lamper Tengah	4800	5021	672	886	0,76	77,96	74,30	F
	Jl. Brigjend Sudiarto (Go Straight)	5100	4730	2177	1948	1,12	296,09	84,20	F
	Jl. Brigjend Sudiarto (Right)	2100	2061	284	364	0,78	79,96	82,51	F
						0,92	140,56	88,49	F

The results of the intersection performance analysis at the afternoon peak hour on Tuesday, August 27, 2024, showed that both the Gayamsari and Lamper intersections still experienced heavy traffic conditions with a low level of service. The average degree of saturation of the Lamper intersection in the afternoon hour is 0.92 with an average delay of 88.49 seconds, which is still classified as service category F. These results indicate that the existing signal system has not been able to accommodate traffic flow efficiently, and adjustments to cycle times and signal coordination are needed to improve overall intersection performance.

Table 3. Existing Intersection Performance Morning Peak Hour, Saturday, August 24, 2024

Intersection	Location	J_0	J	q	C	D_J	P_A	T	LOS
Gayamsari	Jl. Exit Tol Gayamsari	5400	4766	673	681	0,99	70,07	92,82	F
	Jl. Majapahit (East –Turn Right)	3000	3069	729	1535	0,48	74,20	26,12	D
	Jl. Majapahit (West)	5400	4846	1251	1211	1,03	125,68	79,03	F
Lamper	Jl. Gajah Raya	4200	4058	633	657	0,96	100,43	103,26	F
	Jl. Majapahit (Go Straight)	5100	4680	1449	1894	0,77	143,82	50,02	E
	Jl. Majapahit (Turn Right)	2100	2074	227	240	0,95	86,52	145,57	F

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	Jl. Lamper Tengah	4800	4947	659	1001	0,66	74,00	68,64	F
	Jl. Brigjend Sudiarto (Go Straight)	5100	4598	784	1860	0,42	63,60	39,92	D
	Jl. Brigjend Sudiarto (Right)	2100	2106	177	243	0,73	51,36	89,44	F
						0,78	87,74	77,20	F

Analysis of intersection performance during the weekend morning peak hour shows that despite a decrease in traffic volumes compared to weekdays, most of the approaches at the Gayamsari and Lamper intersections still experience non-optimal service conditions. Overall, the average intersection showed a degree of saturation of 0.78 and a delay of 77.20 seconds, thus remaining in service category F. These findings reinforce the indication that the current signal system is not optimal in regulating traffic flow, even on weekend days, so signal coordination planning and cycle time adjustments are needed to improve the efficiency and quality of traffic service at both intersections.

Table 4. Existing Intersection Performance Afternoon Peak Hour, Saturday, August 24, 2024

Intersection	Location	J_0	J	q	C	D_J	P_A	T	LOS
Gayamsari	Jl. Exit Tol Gayamsari	5400	4909	1014	846	1,20	133,04	140,84	F
	Jl. Majapahit (East-Turn Right)	3000	3106	721	964	0,75	108,00	52,02	E
	Jl. Majapahit (West)	5400	4929	1413	2040	0,87	150,33	46,74	E
Lamper	Jl. Gajah Raya	4200	4055	488	477	1,02	87,84	137,67	F
	Jl. Majapahit (Go Straight)	5100	4687	1414	1930	0,73	134,29	47,15	E
	Jl. Majapahit (Turn Right)	2100	2097	295	370	0,80	83,95	84,05	F
	Jl. Lamper Tengah	4800	4923	632	869	0,73	72,44	73,05	F
	Jl. Brigjend Sudiarto (Go Straight)	5100	4700	1599	1935	0,83	162,39	51,35	E
	Jl. Brigjend Sudiarto (Right)	2100	2068	232	365	0,63	60,01	72,05	F
						0,84	110,26	78,32	F

In the weekend afternoon peak hour, the existing conditions of the Gayamsari and Lamper intersections show traffic performance that is still not optimal, with most approaches at a low level of service. The average performance of the Lamper intersection in this hour showed a DJ of 0.84 and an average delay of 78.32 seconds, which overall placed the intersection in service category F. This condition shows that although the traffic load on weekends is slightly

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lower than on weekdays, the existing signal system is still unable to manage traffic flow efficiently, so improvements in the form of signal coordination between intersections and cycle time resetting are needed to improve traffic performance in the corridor.

Intersection New Cycle Time Planning

Table 5. Recapitulation of Cycle Time and Green Time Planning on Active Days

Intersection	Location	Cycle Time and Green Planning I			Cycle Time and Green Planning II			Cycle Time and Green Planning III			Cycle Time and Green Planning IV			Cycle Time and Green Planning V		
		s	Morn	Aftn	s	Morn	Aftn	s	Morn	Aftn	s	Morn	Aftn	s	Morn	Aftn
Gayamsari	Jl. Exit Tol Gayamsari	172	37	37	167	36	36	169	36	36	130	27	27	180	39	38
	Jl. Majapahit (East-Turn Right)	172	60	41	167	58	40	169	59	41	130	44	30	180	68	48
	Jl. Majapahit (West)	172	60	79	167	58	76	169	59	77	130	44	58	180	58	79
Lamper	Jl. Gajah Raya	172	18	15	167	17	14	169	18	14	130	13	11	180	32	27
	Jl. Majapahit (Go Straight)	172	88	89	167	85	86	169	86	87	130	64	64	180	77	82
	Jl. Brigjend Sudiarto (Go Straight)	172	88	89	167	85	86	169	86	87	130	64	64	180	77	82
	Jl. Lamper Tengah	172	23	16	167	22	16	169	22	16	130	16	12	180	34	28
	Jl. Majapahit (Turn Right)	172	23	32	167	22	31	169	23	32	130	17	23	180	22	28
	Jl. Brigjend Sudiarto (Right)	172	23	32	167	22	31	169	23	32	130	17	23	180	22	28

Based on the recapitulation of cycle time planning and green time allocation on active days, five planning scenarios were carried out with variations in cycle duration ranging from 130 seconds to 180 seconds. Each planning is tested at both intersections with green time adjustments for each approach during the morning and afternoon peak hours. From the comparison results, it is known that the V planning with a cycle time of 180 seconds provides a more proportionate and flexible distribution of green time to accommodate high traffic volumes, especially on main approaches such as Jalan Majapahit in the straight direction and the Gayamsari intersection in the west direction and the toll exit. For example, in plan V, the green time for the approach of Jalan Majapahit (west) at the Gayamsari intersection reached 58 seconds (morning) and 79 seconds (afternoon), which was greater than the green time allocation in other planning. The same can be seen at the Lamper intersection, where mainstream approaches such as Jalan Majapahit straight and Brigadier General Sudiarto straight get a considerable green allocation, which is 77–82 seconds, which is very important to facilitate vehicle platoons in signal coordination. This 180-second cycle planning was chosen as the best cycle time because it results in a balanced distribution of green time between approaches, is able to reduce delays and queue lengths, and supports the creation of an effective green wave pattern in coordination between intersections.

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Table 6. Weekend Cycle Time and Green Time Planning Recapitulation

Intersection	Location	Cycle Time and Green Planning I			Cycle Time and Green Planning II			Cycle Time and Green Planning III			Cycle Time and Green Planning IV			Cycle Time and Green Planning V		
		s	Morn	Aftn	s	Morn	Aftn	s	Morn	Aftn	s	Morn	Aftn	Aftn	Morn	Aftn
Gayamsari	Jl. Exit Tol Gayamsari	76	14	16	81	15	17	79	14	17	130	25	30	130	30	29
	Jl. Majapahit (East-Turn Right)	76	23	18	81	25	19	79	24	19	130	43	33	130	44	35
	Jl. Majapahit (West)	76	25	28	81	27	30	79	26	29	130	47	52	130	41	51
Lamper	Jl. Gajah Raya	76	9	6	81	10	7	79	10	7	130	18	12	130	24	19
	Jl. Majapahit (Go Straight)	76	28	34	81	31	37	79	29	36	130	55	66	130	47	49
	Jl. Brigjend Sudiarto (Go Straight)	76	28	34	81	31	37	79	29	36	130	55	66	130	47	49
	Jl. Lamper Tengah	76	8	7	81	8	7	79	8	7	130	15	13	130	21	21
	Jl. Majapahit (Turn Right)	76	11	9	81	12	10	79	12	10	130	22	18	130	18	21
	Jl. Brigjend Sudiarto (Right)	76	11	9	81	12	10	79	12	10	130	22	18	130	18	21

The recapitulation of cycle time planning and green time allocation on weekends shows that there are five planning alternatives with cycle variations between 76 seconds and 130 seconds. Based on the analysis, planning with a 130-second cycle** (Plans IV and V) provides more adequate green time allocation, especially on approaches with dominant traffic volumes. For example, at the Gayamsari intersection the approach to Jalan Majapahit (west) received a green time of 47 seconds (morning) and 52 seconds (afternoon) under Planning IV, compared to only 25-30 seconds under the shorter cycle plan. Similarly, at the Lamper intersection, the approaches to Jalan Majapahit straight and Brigjen Sudiarto straight received optimal green times of 55-66 seconds each, allowing for a smoother and more coordinated flow of vehicles. In general, the 130-second cycle time proved to be able to provide a more balanced and proportional green distribution for all approaches compared to scenarios with shorter cycle times (76-81 seconds), which tend to result in narrow green time distributions and potentially increase queue lengths. Therefore, the 130-second cycle was selected as the best option for weekend planning to support effective signal coordination and improved traffic performance between intersections.

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Best Performance Planning Assessment Intersection

Table 7. Planning Performance Assessment of Active Day Morning Peak Hour Intersection

Plan	Cycle Time	Value Weight						Value Weight Total
	(s)	D_J	Value Weight D_J	P_A (m)	Value Weight P_A	T (second)	Value Weight T	
I	172	1,069	4,0	186	1,0	168	1,0	6,0
II	167	1,073	2,0	181	3,0	165	3,0	8,0
III	169	1,071	3,0	183	2,0	167	2,0	7,0
IV	130	1,113	1,0	149	5,0	84	5,0	11,0
V	180	0,995	5,0	177	4,0	103	4,0	13,0

Based on the table of assessment results above, it can be determined that the cycle time planning with the best performance is planning V because it has the assessment results with the greatest value compared to other plans. Thus, planning V will be used to design signal coordination between intersections during the morning peak hour on weekdays.

Table 8. Assessment of Performance Planning for the Weekday Afternoon Peak Hour Intersection

Plan	Cycle Time	Value Weight						Value Weight Total
	(s)	D_J	Value Weight D_J	P_A (m)	Value Weight P_A	T (second)	Value Weight T	
I	172	1,056	4,0	225	1,0	186	1,0	6,0
II	167	1,060	2,0	219	4,0	183	3,0	9,0
III	169	1,058	3,0	222	3,0	184	2,0	8,0
IV	130	1,098	1,0	181	5,0	93	5,0	11,0
V	180	0,964	5,0	223	2,0	96	4,0	11,0

Based on the table of assessment results above, it can be determined that the cycle time planning with the best performance is planning V because it has the assessment results with the greatest value compared to other plans. Thus, planning V will be used to design signal coordination between intersections during the afternoon peak hour on weekdays.

Table 9. Weekend Morning Peak Hour Intersection Performance Planning Assessment

Plan	Cycle Time	Value Weight						Value Weight Total
	(s)	D_J	Value Weight D_J	P_A (m)	Value Weight P_A	T (second)	Value Weight T	
I	76	0,911	1,0	61	5,0	66,7	3,0	9,0
II	81	0,893	3,0	63	3,0	66,8	2,0	8,0
III	79	0,902	2,0	62	4,0	66,6	4,0	10,0
IV	130	0,805	4,0	89	1,0	76,4	1,0	6,0
V	130	0,777	5,0	84	2,0	58,6	5,0	12,0

Based on the table of assessment results above, it can be determined that the cycle time planning with the best performance is planning V because it has the assessment results with the greatest value compared to other plans. Thus, planning V will be used to design signal coordination between intersections during the morning peak hour on weekends.

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Table 10. Assessment of Performance Planning of Weekend Afternoon Peak Hour Intersections

Plan	Cycle Time	Value Weight						Value Weight Total
	(s)	D_J	Value Weight D_J	P_A (m)	Value Weight P_A	T (second)	Value Weight T	
I	76	1,116	1,0	90	5,0	117	1,0	7,0
II	81	1,095	3,0	93	3,0	100	4,0	10,0
III	79	1,105	2,0	91	4,0	116	2,0	8,0
IV	130	0,986	4,0	125	1,0	106	3,0	8,0
V	130	0,896	5,0	121	2,0	64	5,0	12,0

Based on the table of assessment results above, it can be determined that the cycle time planning with the best performance is planning V because it has the assessment results with the greatest value compared to other plans. Thus, planning V will be used to design signal coordination between intersections during the afternoon peak hour on weekends.

Design of Interchange Signal Coordination on Active Days

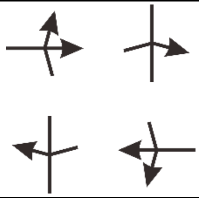
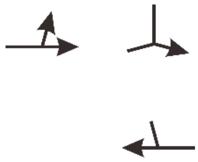
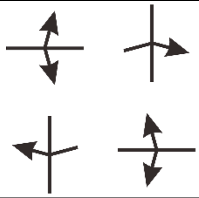
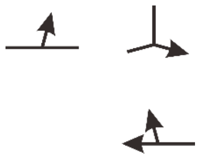
After getting the cycle time with the best performance on weekdays, the next stage is planning coordination between intersections. The planning stage for coordination between intersections in this study will use the planned speed according to the results of field observations, namely 40 km / h and the travel time between intersections is 45 seconds.

Intersection Signal Coordination at Morning Peak Hour

The travel time that has been obtained previously will be used as an offset time to show the platoon movement trajectory on the inter-intersection coordination diagram. Furthermore, the green signal turn-on time of each intersection is adjusted to the next trajectory by shifting horizontally, so that the group of vehicles passing the green signal at the first intersection will get a green signal at the second intersection.

Before conducting signal coordination, it is necessary to know the phase movements at both intersections. In this study, the existing phase movement sequence at the intersection was changed, where this phase movement was also used in the afternoon peak hour on weekdays and the morning peak hour and afternoon peak hour on weekends. The change in phase movement order is done to place phase movements in the same direction in the same phase sequence. Thus signal coordination between intersections can be done. The phase movements can be seen in the table below.

Table 11. Phase Movement at Lamper Intersection and Gayamsari Intersection

Phase	Intersection Lamper		Intersection Gayamsari	
1		Straight Direction Brigjen Sudiarto Street and Majapahit Street Green Signal		Westbound Majapahit Road Straight Direction Green Signal
2		Right Turn on Brigjen Sudiarto Street and Majapahit Street Green Signal		Right Turn on Majapahit Road from East Direction Green Signal

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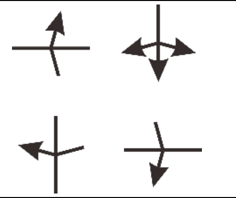
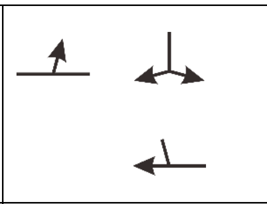
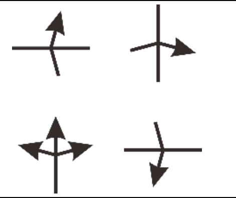
3		Gajah Raya Street Green Signal		Right Turn Toll Exit Green Signal
4		Lamper Tengah Street Green Signal	-	-

The phase diagrams for both intersections are made according to the cycle time based on the results of the previous V planning, which can be seen in the figure below.

Figure 2. Phase Diagram of Gayamsari Intersection Active Morning Peak Hour

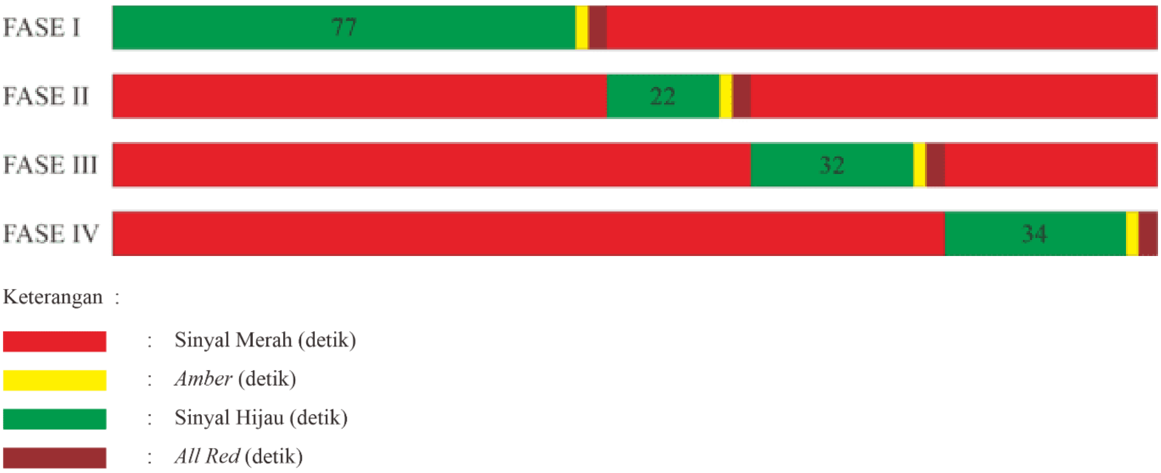


Figure 3. Lamper Intersection Phase Diagram Active Morning Peak Hour

After knowing the phase movement and phase diagram of the two intersections, coordination can then be carried out at the two intersections with the previously obtained offset time of 45 seconds. The offset time is a description of the platoon movement trajectory and bandwidth as a large description of the trajectory in the coordination diagram. One of the bandwidth requirements in the coordination diagram is that the trajectory is not allowed to reach the red signal at the next intersection to get an uninterrupted flow.

If in the coordination diagram there is a trajectory that hits the red signal at the next intersection, then the cycle time must be shifted until it finds the right position or does not touch the red signal at the next intersection. Another way that can be done is to minimize the

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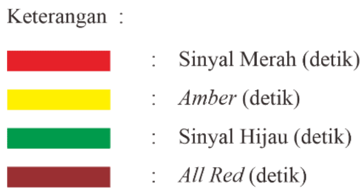

size of the trajectory, thus the bandwidth requirements can be met. Furthermore, the coordination flow diagram of the morning peak hour intersection on weekdays with the new cycle time according to the results of planning V can be seen in the following figure.

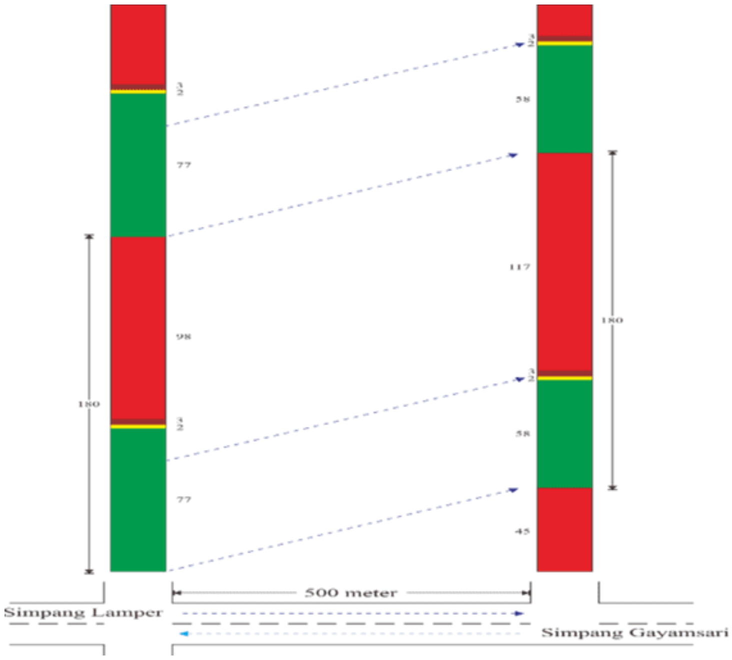

Figure 4. Active Morning Peak Hour Intersection Coordination Flow Diagram

Based on the coordination flow diagram above, we can see that the two intersections, namely Gayamsari Intersection and Lamper Intersection, are coordinated. The offset time used is the same as the travel time between intersections during field observations, which is 45 seconds and the bandwidth obtained from west to east, (from Lamper intersection to Gayamsari intersection) is 60 seconds. Thus the results of the intersection coordination calculation can be used during the morning peak hour on active days.

However, this coordination can only be applied from the Lamper intersection to the Gayamsari intersection (from west to east), while from the Gayamsari intersection to the Lamper intersection (from east to west) cannot be coordinated. because at the Gayamsari intersection the vehicle straight to the Lamper intersection does not get a red signal.

Afternoon Peak Hour Intersection Coordination

The calculation of coordination between intersections in the afternoon peak hour is carried out in the same way as the calculation of coordination in the morning peak hour. By maintaining the existing phase movement at the intersection as in the morning peak hour. For phase diagrams at both intersections are made according to the cycle time based on the results of the previous V planning, which can be seen in the figure below.

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Figure 5. Phase Diagram of Gayamsari Intersection Active Afternoon Peak Hour

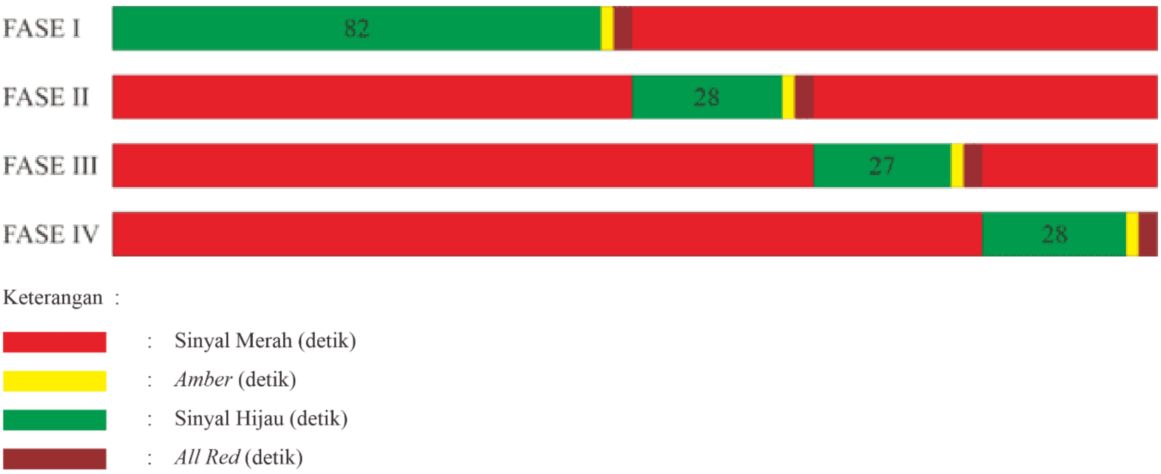

Figure 6. Phase Diagram of Lamper Intersection Afternoon Peak Hours on Active Days

Furthermore, the coordination flow diagram for the afternoon peak hour intersection on active days can be seen in the figure below.

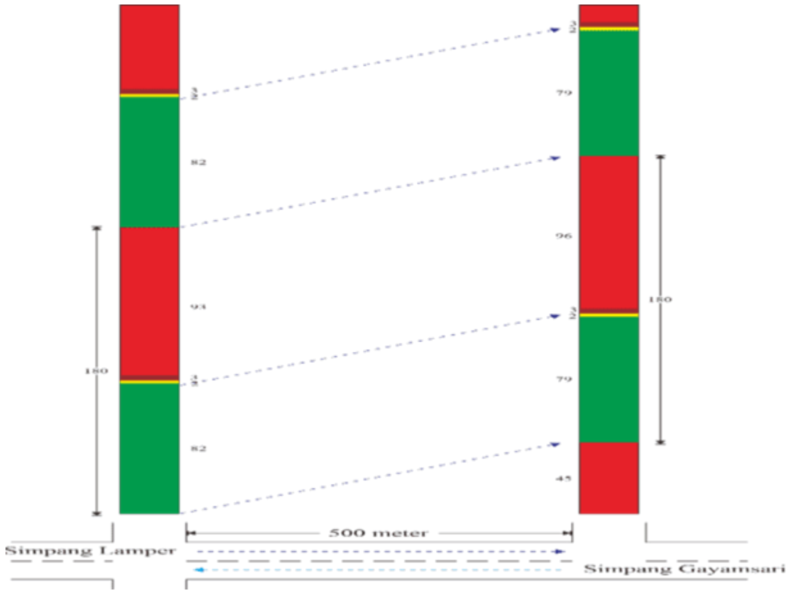

Figure 7. Active Afternoon Peak Hour Intersection Coordination Flow Diagram

Based on the coordination flow diagram above, the bandwidth from Lamper intersection to Gayamsari intersection is 81 seconds. Thus the results of the intersection coordination calculation can be used during the afternoon peak hour on active days. However, the coordination cannot be applied from the Gayamsari intersection to the Lamper intersection, because at the Gayamsari intersection straight vehicles do not get a red signal.

Design of Signal Coordination between Intersections on Weekends

After getting the cycle time with the best performance on weekends, the next stage is planning coordination between intersections. The planning stage of coordination between intersections in this study will use the planned speed according to the results of field observations, namely 40 km / h and the travel time between intersections is 45 seconds.

Inter-intersection Coordination at Morning Peak Hour

Just like the coordination calculation on weekdays, the coordination calculation on weekends also maintains the existing phase movements at both intersections. For phase diagrams at both

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intersections are made according to the cycle time based on the results of the previous V planning, which can be seen in the figure below.

Figure 8. Phase Diagram of Gayamsari Intersection Weekend Morning Peak Hour

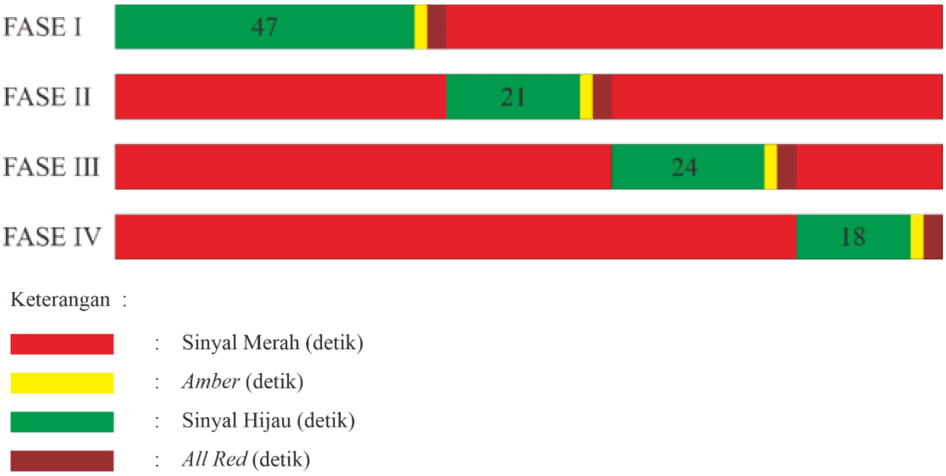

Figure 9. Lamper Intersection Phase Diagram Weekend Morning Peak Hours

Furthermore, the coordination flow diagram for the morning peak hour intersection on weekends can be seen in the figure below.

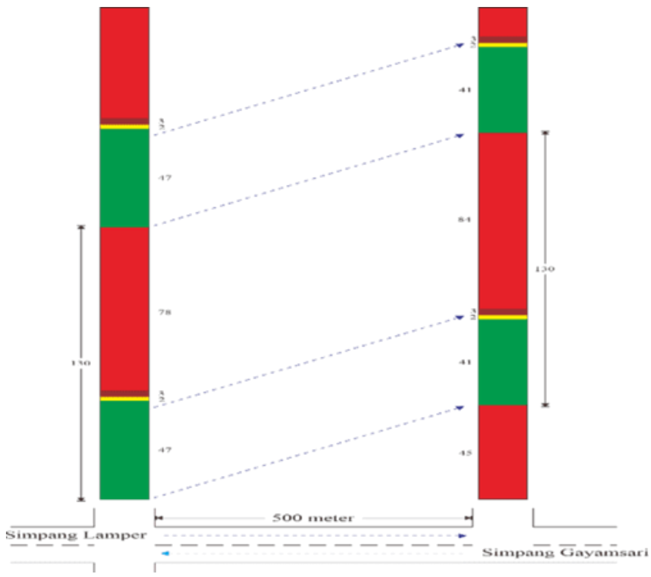

Figure 10. Weekend Morning Peak Hour Intersection Coordination Flow Diagram

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Based on the coordination flow diagram above, the bandwidth from Lamper intersection to Gayamsari intersection is 43 seconds. Thus the results of the intersection coordination calculation can be used during the morning peak hour on weekends. However, the coordination cannot be applied from the Gayamsari intersection to the Lamper intersection, because at the Gayamsari intersection straight vehicles do not get a red signal.

Inter-intersection Coordination at the Afternoon Peak Hour

Just like the coordination calculation on weekdays, the coordination calculation on weekends also maintains the existing phase movement at the intersection. The phase diagrams for both intersections are made according to the cycle time based on the results of the previous V planning, which can be seen in the figure below.

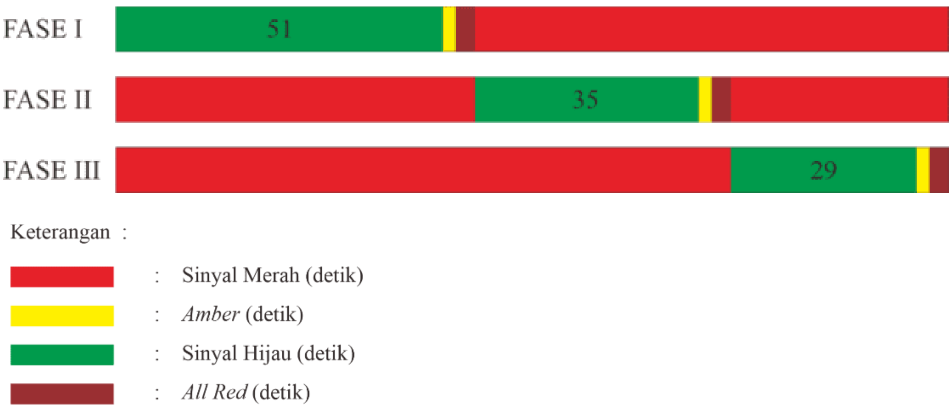

Figure 11. Phase Diagram of Gayamsari Intersection During Weekend Evening Peak Hour

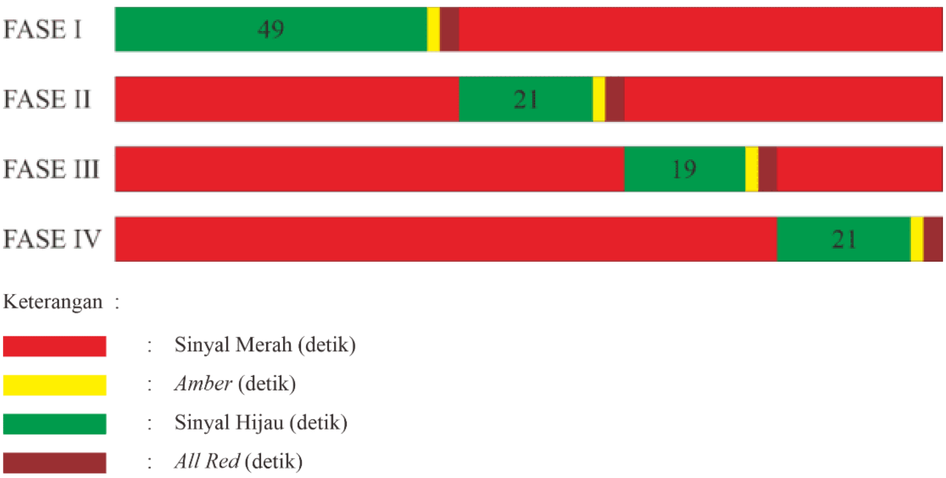

Figure 12. Phase Diagram of Gayamsari Intersection During Weekend Evening Peak Hour

Furthermore, the flow diagram for signal coordination during the weekend morning peak hour can be seen in the figure below:

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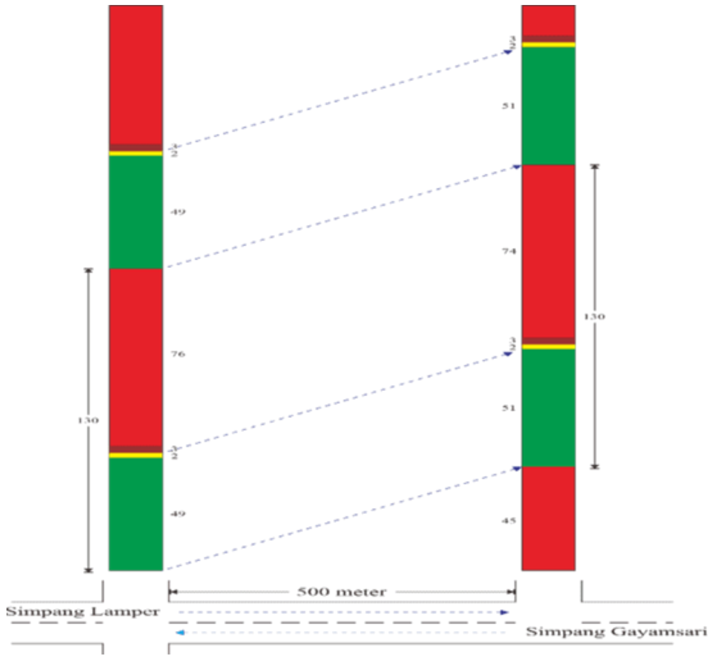

Figure 13. Signal Coordination Flow Diagram During Weekend Evening Peak Hour

Based on the coordination flow diagram above, the bandwidth from Lamper Intersection to Gayamsari Intersection is 51 seconds. Thus, the results of this intersection coordination calculation can be applied during the morning peak hour on weekends. However, the same coordination cannot be applied in the opposite direction (from Gayamsari to Lamper) because vehicles traveling straight at the Gayamsari Intersection do not encounter a red signal phase.

Conclusion

Based on the analysis and planning conducted for the Gayamsari and Lamper intersections in Semarang City, it can be concluded that under existing conditions during the weekday morning peak hours (based on observations over three active days: Monday, Tuesday, and Wednesday), the best performance was recorded with a saturation degree (D_J) of 1.00, a queue length (P_A) of 144.90 meters, and a delay (T) of 105.81 seconds. Meanwhile, during weekend observations (Saturday and Sunday), the best performance was achieved with a D_J of 0.78, P_A of 87.74 meters, and T of 77.20 seconds. For the weekday evening peak hours, the best observed performance showed a D_J of 0.92, P_A of 140.56 meters, and T of 88.49 seconds, while the weekend evening peak hours yielded D_J 0.84, P_A 110.26 meters, and T 78.32 seconds.

According to the simulation results from Planning Scenarios I to V, Scenario V delivered the best average intersection performance. During the weekday morning peak, it achieved a D_J of 0.995, P_A of 177.21 meters, and T of 102.62 seconds. For the weekend morning peak, the performance improved further with a D_J of 0.777, P_A of 83.76 meters, and T of 58.59 seconds. Meanwhile, the weekday evening peak under Scenario V produced a D_J of 0.964, P_A of 222.45 meters, and T of 95.82 seconds, and for the weekend evening peak, the values were D_J 0.896, P_A 121.24 meters, and T 64.37 seconds.

Signal coordination between intersections can only be applied in the direction from Lamper to Gayamsari (west to east). Conversely, coordination from Gayamsari to Lamper (east to west) is not feasible because vehicles traveling straight through the Gayamsari Intersection do not encounter a red light and are allowed to proceed continuously. Based on the signal coordination flow diagram, the calculated offset time between the intersections is 45 seconds, while the bandwidth times are as follows: 60 seconds during the weekday morning peak, 81

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seconds during the weekday evening peak, 43 seconds during the weekend morning peak, and 51 seconds during the weekend evening peak.

It is recommended that the designed signal coordination between Gayamsari and Lamper intersections be implemented in practice by the relevant authorities, particularly the Semarang City Transportation Department, to reduce delays and queue lengths along this corridor. In addition, routine monitoring and evaluation of signal coordination effectiveness should be carried out, especially when significant traffic volume changes occur due to new developments, land use changes, or traffic management policies. For further improvement, the use of adaptive systems based on sensors or traffic-responsive signal control is suggested to dynamically adjust signal timing to current traffic conditions.

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