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Signalized Intersection Optimization Using PKJI 2023 And Webster For Emission Reduction

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Abstract

This research is motivated by the increasing traffic volume in Bantul Regency, which has led to a decline in the performance of signalized intersections and an increase in motor vehicle emissions. The purpose of this study is to evaluate the performance of Klangon 3-way intersection, Sedayu 4-way intersection, and Pedes 4-way intersection and to analyze the effectiveness of optimization using PKJI 2023 and the Webster method on traffic performance and emissions. This study uses a quantitative, descriptive, evaluative approach. The study population is all vehicle flows at signalized intersections, while the sample is determined by purposive sampling based on high-volume intersections during peak hours. The research instruments include a CTMC survey, intersection inventory forms, and geometric measurements. Data analysis techniques are carried out using PKJI 2023 to calculate capacity, degree of saturation, delay, and queue length, as well as the Webster method for signal time optimization, followed by emission estimation based on the LAPI-ITB model. The results showed that the Webster method significantly reduced delays and queue lengths, while the combined scenario provided the best results, with a delay reduction of up to 66.29 percent and reduced emissions due to reduced vehicle idle time. The study concluded that signal optimization and intersection geometric improvements are effective in improving traffic performance while reducing vehicle emissions.

Keywords: ***Emission Reduction, PKJI 2023, Signalized Intersection, Traffic Delay, Webster Method***

INTRODUCTION

Bantul Regency's population growth, which will reach 1,025,750 people by 2025, will result in increased community mobility and motorized vehicle use. This will increase traffic volumes along the strategic corridor connecting Kulon Progo Regency, Bantul, and Yogyakarta City, potentially degrading road network performance, particularly at intersections (Bantul Regency Central Statistics Agency, 2025; Hendri *et al*., 2022).

Signalized intersections are critical points in the transportation system because they regulate vehicle movement from various directions. Increased traffic volume can lead to increased saturation, queue lengths, and vehicle delays, thereby reducing intersection service levels and travel efficiency (Natsir, 2018; Ummiyah & Patriotika, 2024).

These problems are evident at the Klangon 3-way intersection, Sedayu 4-way intersection, and Pedes 4-way intersection, which have relatively high levels of saturation, accompanied by significant queues and delays during peak hours. Furthermore, the dominance of motorcycles and the diversity of vehicle types passing through them have made operational conditions at these intersections increasingly complex (AS Pratama *et al*., 2022; Dali *et al*., 2024).

Suboptimal intersection performance not only causes congestion but also increases fuel consumption and vehicle exhaust emissions due to repeated stopping and acceleration at signalized intersections. This condition has the potential to worsen air quality in the Sedayu corridor and surrounding areas, which experience high traffic activity (Iqbal & Muammar, 2022; Bantul Regency Environmental Agency, 2023).

Based on these conditions, this study aims to evaluate the performance of Klangon Intersection 3, Sedayu Intersection 4, and Pedes Intersection 4 and develop alternative performance improvements using PKJI 2023 and the Webster method. The urgency of this research lies in the importance of maintaining smooth mobility in the strategic corridors of Bantul Regency, while its novelty lies in the simultaneous integration of intersection performance analysis and vehicle emission estimates at three intersections within one research corridor (Iscahyono & Yulindar, 2023; Kharisma, 2024).

RESEARCH METHODS

This study uses a quantitative approach with a descriptive evaluative method to assess the performance of signalized intersections and their impact on motor vehicle exhaust emissions under existing conditions and after optimization. This approach was chosen because it allows for objective measurement of traffic variables based on numerical data such as saturation levels, delays, and queue lengths (Sugiyono, 2022; Creswell & Creswell, 2023). The analysis was conducted at three intersections in Bantul Regency, namely Klangon Intersection 3, Sedayu Intersection 4, and Pedes Intersection 4, by comparing existing conditions and the results of optimization scenarios using the Webster method and referring to PKJI 2023 and Regulation of the Minister of Environment Number 12 of 2010.

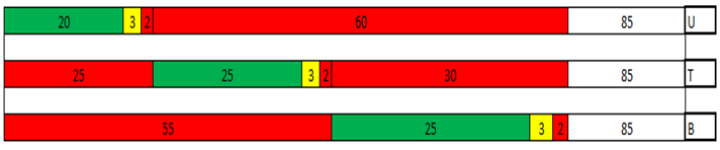
The population in this study was all vehicle traffic flowing through signalized intersections at the study location, including vehicles traveling straight, turning left, and turning right during peak hours. The sample was determined using purposive sampling by selecting intersections with high traffic volumes, using APILL, and showing indications of intersection performance problems. Sample data were obtained through CTMC surveys during morning, afternoon, and evening rush hours to obtain classified vehicle volume data, queue lengths, and delays, in accordance with sampling principles relevant to the research objectives (Sudaryono, 2022; Creswell & Creswell, 2023).

The research instruments included CTMC survey sheets, intersection inventory forms, geometric measuring instruments (roll meters and walking measures), field documentation, and data processing software. Primary data were obtained from field surveys in the form of intersection geometric conditions, traffic volumes, and delays and queues, while secondary data came from related agencies and regulations such as DPUPKP Bantul, BPS, PKJI 2023, Law No. 22 of 2009, and Regulation of the Minister of Environment No. 12 of 2010. Analysis was carried out quantitatively through calculating the performance of existing intersections, optimizing the Webster method, and estimating idle emissions based on the LAPI-ITB and Guttikunda (2009) models, then the results were compared to assess the effectiveness of improving intersection performance (Emzir, 2024; Sugiyono, 2022).

The research procedure begins with identifying intersection performance issues based on field conditions, followed by collecting primary and secondary data through surveys and literature studies. The data obtained is then processed using the PKJI 2023 approach to calculate saturation flow, capacity, degree of saturation, queue length, and delay. Cycle time optimization is then performed using the Webster method to generate intersection performance improvement scenarios. The final stage is an analysis of idle exhaust emissions and a comparison of existing and optimized results to generate the most effective recommendations for improving traffic performance and reducing vehicle emissions.

RESULTS AND DISCUSSION

Optimizing Traffic Handling



Picture 1 Existing cycle time diagram of Klangon 3-way intersection
Source: Analysis, 2026

Table 1. Degree of Saturation of the Three Intersections

Name Simpang	Indicator	Approach		
		N	E	W
Simpang 3 Klangon	Traffic Flow (Q)	258,15	645,30	530,80
	Saturation Flow (S)	1850	2550	1975
	Flow Ratio (y = q/s)	0,14	0,25	0,27
	Le (m)	3	5	4
	Y = yu+yt+yb	0,66		

Source: Analysis, 2026

Picture 2. Cycle Time Diagram of Klangon 3-Way Intersection with the Method *Webster*
Source: Analysis, 2026

Based on Figure 2, the signal design for the Klangon 3-way intersection using the Webster method yields a cycle time of 76 seconds, divided into three phases: north, east, and west. The green time for each phase is 13 seconds, 23 seconds, and 25 seconds, respectively, with an additional 3 seconds of yellow and 2 seconds of all-red as transition times. This division is based on the morning peak hour traffic volume, which represents the intersection's highest load conditions.

Table 2. Degree of Saturation of Klangon 3-way Intersection *Webster*

SIMPANG 3 KLANGON	Volume (q)	Capacity	Degree Of Saturation
NORTH	258,15	316,45	0,82
EAST	645,30	771,71	0,84
WEST	530,80	649,67	0,82
Average Degree Of Saturation			0,82

Source: Analysis, 2026

Table 3. Klangon 3-way Intersection Delay Calculation Data

A	B	M	Percentage	C
0,3467	0,01	5,45	6,57%	1,74
0,2383	0,05	11,21	2,57%	0,47
0,2501	0,04	13,62	2,15%	0,41

Source: Analysis, 2026

Table 4. Klangon 3-way Intersection Delay *Webster*

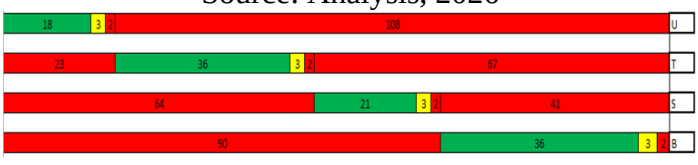
SIMPANG 3 KLANGON	Delay (d)
NORTH	24,77
EAST	18,83
WEST	17,97
Average Delay (sec/smp)	20,52

Source: Analysis, 2026

Table 5. Long Queue at Klangon 3-Way Intersection *Webster*

SIMPANG 3 KLANGON	r (seconds)	N (smp)	conversion (meters)
NORTH	60,50	3,94	19,72
EAST	49,51	7,81	39,07
WEST	47,99	6,19	30,94

Source: Analysis, 2026

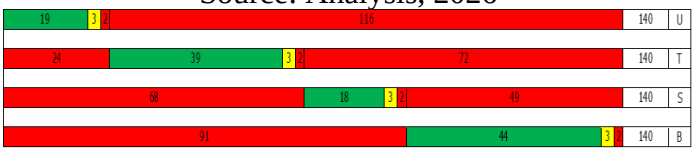


Picture 3. Existing Cycle Time Diagram of Sedayu 4-Way Intersection
Source: Analysis, 2026

Table 6. Cycle Time Calculation Data Using the *Webster* Method at Sedayu 4-Way Intersection

Name Simpang	Indicator	Approach			
		N	E	S	W
Simpang 4 Sedayu	Traffic Flow (Q)	165,10	628,80	216,80	709,65
	Saturation Flow (S)	1313	2550	1850	2550
	Flow Ratio (y = q/s)	0,13	0,25	0,12	0,28
	Le (m)	2,5	5	3	5
	Y = yu+yt+ys+yb	0,77			

Source: Analysis, 2026



Picture 4. Cycle Time Diagram of Sedayu 4-Way Intersection Using *Webster* Method

Source: Analysis, 2026

Based on Figure 4, the signal design for the Sedayu 4-way intersection using the Webster method results in a 140-second cycle time divided into four phases (north, east, south, and west). The green time for each phase is 19 seconds, 39 seconds, 18 seconds, and 44 seconds, with an additional 3 seconds of yellow and 2 seconds of all-red traffic at each phase change. This division is based on the morning rush hour traffic volume, which is the intersection's highest load condition.

Table 7. Degree Of Saturation Sedayu 4-Way Intersection *Webster*

SIMPANG 4 SEDAYU	Volume (q)	Capacity	Degree Of Saturation
NORTH	165,10	178,19	0,93
EAST	628,80	710,36	0,89
SOUTH	216,80	237,86	0,91
WEST	709,65	801,43	0,89
Average Degree Of Saturation			0,90

Source: Analysis, 2026

Table 8. Delay Calculation Data for Sedayu Intersection 4

A	B	M	Percentage	C
0,3723	0,01	6,42	5,94%	3,11
0,2753	0,04	24,45	1,29%	0,50
0,3800	0,01	8,43	4,60%	2,45
0,2531	0,05	27,60	1,11%	0,40

Source: Analysis, 2026

Table 9. Delays at Sedayu Intersection 4 *Webster*

SIMPANG 4 SEDAYU	Delay (d)
NORTH	49,21
EAST	38,27
SOUTH	50,87
WEST	35,31
Average Delay (sec/smp)	43,42

Source: Analysis, 2026

Table 10. Long Queue at Sedayu 4-Way Intersection *Webster*

SIMPANG 4 SEDAYU	r (seconds)	N (smp)	conversion (meters)
NORTH	116,69	4,93	24,66
EAST	98,18	15,26	76,30
SOUTH	118,07	6,62	33,10
WEST	93,06	16,13	80,66

Source: Analysis, 2026

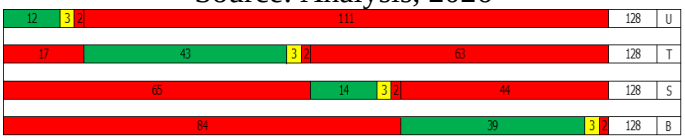
Picture 5. Existing Cycle Time Diagram of Pedes 4-Way Intersection

Source: Analysis, 2026

Table 11. Cycle Time Calculation Data with Method *Webster* Pedes 4-way intersection

Name Simpang	Indicator	Approach			
		N	E	S	W
Simpang 4 Pedes	Traffic Flow (Q)	159,60	748,45	101,55	685,75
	Saturation Flow (S)	1850	2550	1050	2550
	Flow Ratio (y = q/s)	0,09	0,29	0,10	0,27
	Le (m)	3	5	2	5
	Y = yu+yt+ys+yb	0,75			

Source: Analysis, 2026



Picture 6. Cycle Time Diagram of Pedes 4-Way Intersection with the Method *Webster*

Source: Analysis, 2026

Based on Figure 6, the signal design for the Pedes 4-way intersection using the Webster method results in a cycle time of 128 seconds divided into four phases (north, east, south, and west). The green time for each phase is 12 seconds, 43 seconds, 14 seconds, and 39 seconds, respectively, with an additional 3 seconds of yellow and 2 seconds of all red at each phase change. This division is based on the afternoon rush hour traffic volume as the highest load condition at the intersection.

Table 12. Degree of Saturation of Pedes *Webster* Intersection 4

SIMPANG 4 PEDES	Volume (q)	Capacity	Degree Of Saturation
NORTH	159,60	173,44	0,92
EAST	748,45	856,64	0,87
SOUTH	101,55	114,84	0,88
WEST	685,75	776,95	0,88
Average Degree Of Saturation			0,89

Source: Analysis, 2026

Table 13. Delay Calculation Data for Pedes 4-Way Intersection

A	B	M	Percentage	C
0,4074	0,004	5,67	7,25%	3,79
0,2390	0,06	26,61	1,13%	0,35
0,3973	0,01	3,61	11,15%	5,69
0,2559	0,05	24,38	1,25%	0,41

Source: Analysis, 2026

Table 14. Delays at the *Webster* Pedes 4-Way Intersection

SIMPANG 4 PEDES	Delay (d)
NORTH	48,45
EAST	30,54
SOUTH	45,35
WEST	32,60
Average Delay (sec/smp)	39,23

Source: Analysis, 2026

Table 15. Queue Length at Pedes *Webster* 4-Way Intersection

SIMPANG 4 PEDES	r (seconds)	N (smp)	conversion (meters)
NORTH	112,04	4,63	23,16
EAST	81,90	14,86	74,31
SOUTH	110,47	2,84	14,19
WEST	85,59	14,36	71,81

Source: Analysis, 2026

Table 16. Data on Phase Changes at Klangon 3-Way Intersection

Condition	Number of Phases	Phase 1	Phase 2	Phase 3
Existing	3	North	East	West
Combined Scenario	2	North	East and West	-

Source: Analysis, 2026

Table 17. Geometric Widening Data for Klangon 3-Way Intersection

No	Approach	Existing Effective Width (m)	Widening (m)	Effective Width After Widening (m)
1	North	3	0,50	3,50
2	East	5	0,50	5,50
3	West	4	0,50	4,50

Source: Analysis, 2026

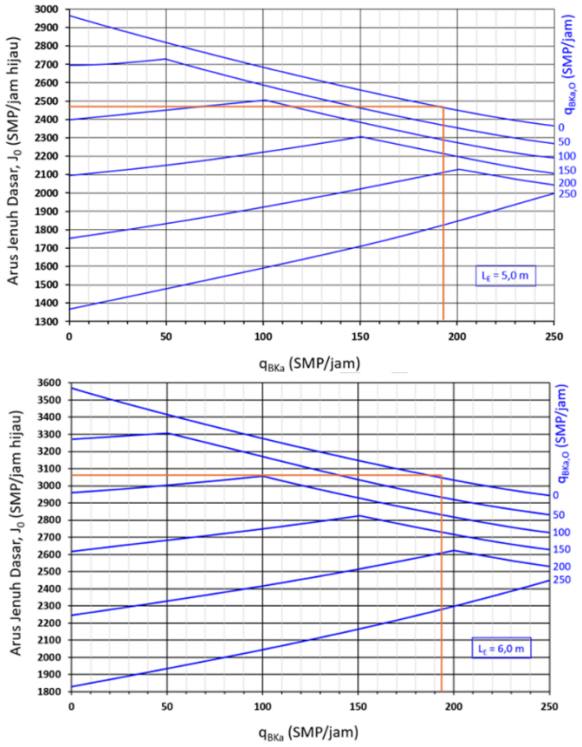
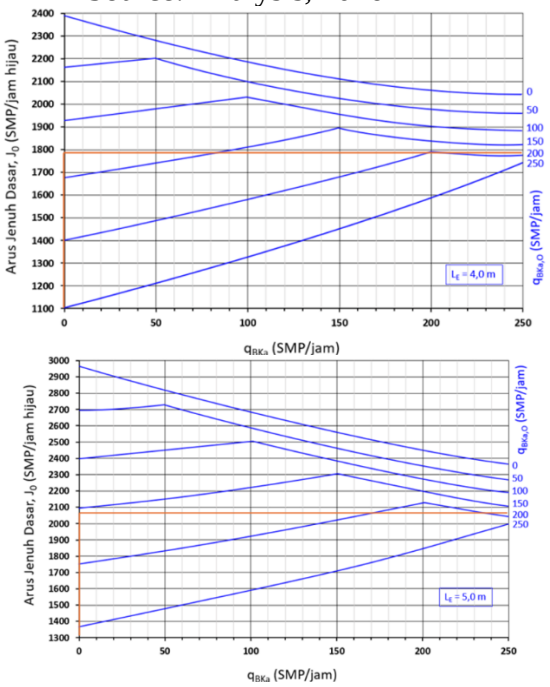


Figure 7 Graph Determining the Base Saturation Flow for the Klangon East Approach Intersection

Source: Analysis, 2026



Picture 7. Graph Determining the Base Saturation Flow of the Klangon 3-Way Intersection, West Approach

Source: Analysis, 2026

Table 17. Basic Saturation Current (J0)

No	Approach	Approach Width (m)	Qbka	Qbka.o	Base Saturation Flow
1	N	3,5	100,6	0	2100
2	E	5,5	193,3	0	2780
3	W	4,5	0	193,3	1935

Source: Analysis, 2026

Table 18. Side Resistance Adjustment Factor (Fhs)

No	Approach	Phase Type	Side Friction	Envorenmental Type	RKTb	FHS
1	N	P	Medium	Commercial	0,029	0,94
2	E	O	Medium	Commercial	0,005	0,94
3	W	O	Medium	Commercial	0,007	0,94

Source: Analysis, 2026

Table 19. Left Turn Adjustment Factor (FBKi)

No	Approach	RBKI	FBKI
1	N	0,6103	0,902
2	E	0	1,000
3	W	0,2301	0,963

Source: Analysis, 2026

Table 20. Right Turn Adjustment Factors (FBKa)

No	Pendekat	RBKA	FBKI
1	N	0,3897	1,101
2	E	0,2121	1,055
3	W	0	1,000

Source: Analysis, 2026

Table 21. Saturated Flow at Klangon 3 Intersection after adjustments

No	Approach	Base Saturation Flow	FHS	FUK	FG	FP	FBKI	FBKA	Saturation Flow (J)
1	N	2100	0,94	1,00	1,00	1,00	0,902	1,10	1.961,72
2	E	2780	0,94	1,00	1,00	1,00	1,000	1,06	2.613,20
3	W	1935	0,94	1,00	1,00	1,00	0,963	1,00	1.818,90

Source: Analysis, 2026

Table 22. Cycle Time Adjustment Values for Klangon 3-Way Intersection$\sum R_{q\ /\ JKritis}$

No	Approach	Traffic Flow	Saturation Flow (J)	Rq/jcritical	Phase Flow (RF)
1	N	258,15	1.961,72	0,13	0,24
2	E	911,3	2.613,20	0,35	0,65
3	W	738,3	1.818,90	0,41	0,76
$\sum R_q/Jcritical$				0,537	

Source: Analysis, 2026

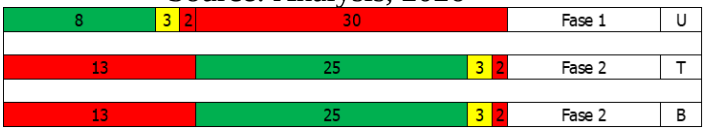


Figure 9. Cycle time diagram of Klangon 3-phase intersection from 3 phases to 2 phases

Source: Analysis, 2026

Table 23. Degree of Saturation After Scenarios (Phase Change, Geometric Widening, and Cycle Time Adjustment)

Road Name	Approach	Green Time per Phase	Volume (Q) smp/jam	Capacity smp/jam	Degree Of Saturation (DS)
Barosan	N	1	258	369	0,70
Batas Kabupaten Kulon Progo - Yogyakarta	E	2	911	1.517	0,60
Batas Kabupaten Kulon Progo - Yogyakarta	W	2	738	1.056	0,70
Average Degree Of Saturation					0,67

Source: Analysis, 2026

Table 24. Queue Length After Scenarios (Phase Change, Geometric Widening, and Cycle Time Adjustment)

Road Name	Approach	Green Time per Phase	Nq	Lm	Queue Length
				Meters	Meters
Barosan	N	1	3,50	3,5	23,36
Batas Kabupaten Kulon Progo - Yogyakarta	E	2	7,30	5,5	29,18
Batas Kabupaten Kulon Progo - Yogyakarta	W	2	6,87	4,5	34,34

Source: Analysis, 2026

Table 25. Delays After Scenarios (Phase Change, Geometric Widening, and Cycle Time Adjustment)

Road Name	Approach	Green Time per Phase	TLL	TG	Average Delay (sec/smp)
Barosan	N	1	22,31	3,97	26,28
Batas Kabupaten Kulon Progo - Yogyakarta	E	2	6,42	2,96	9,38
Batas Kabupaten Kulon Progo - Yogyakarta	W	2	8,47	3,23	11,70
Average delay (sec/smp)					12,56

Source: Analysis, 2026

Motor Vehicle Exhaust Emissions in High Traffic Conditions Before and After Intersection Performance Improvements

The analysis results show that the magnitude of exhaust emissions at all intersections is directly influenced by fuel consumption and vehicle delays at idle conditions. In existing conditions, Klangon 3-way intersection, Sedayu 4-way intersection, and Pedes 4-way intersection experience relatively high delays, ranging from 37 to 62 seconds/smp, resulting in longer vehicle idling times and increased fuel consumption and CO, HC, NOx, PM10, and SO2 emissions. Intersections with the highest traffic volumes and delays produce the largest emissions, while approaches with lower volumes produce smaller emissions, indicating a linear relationship between delays, fuel consumption, and emission loads.

After optimization using the Webster method and combined scenarios that include phase changes, geometric widening, and cycle time adjustments, there was a significant decrease in delays at all intersections to a range of 13 to 43 seconds/pcu. This decrease resulted in reduced vehicle idle time, resulting in consistent fuel consumption and emissions reductions across all approaches. These results indicate that technically improving intersection performance can provide dual benefits, namely improving traffic flow while reducing vehicle emissions, although this study is still limited to peak hour conditions and assumptions of aggregate-based emission calculations. Future research is recommended to include a wider variety of time conditions, weather factors, and microsimulation-based emission models to obtain more comprehensive results and closer to real-world conditions.

Comparison of Performance Before and After Improvements

The comparison results show that the implementation of the Webster method has a positive impact on traffic performance at all three intersections. The degree of saturation experienced a slight increase at all intersections, namely 9.76% to 11.25%, indicating that although signal timing has been optimized, the physical capacity of the intersection has not changed so that the volume-to-capacity ratio continues to increase. However, this condition is still within acceptable limits because the improvements are more focused on the efficiency of green timing and not the addition of geometric capacity.

In contrast, other performance indicators showed significant improvements. Queue length decreased between 26.24% and 41.15%, while delay decreased between 28.53% and 44.93% using the Webster method. In the combined scenario at Klangon Intersection 3, the results obtained were more optimal, with a decrease in the degree of saturation of 9.46%, a decrease in queue length of up to 48.28%, and a decrease in delay of 66.29%. These results indicate that the combination of phase changes, geometric widening, and cycle time adjustments can provide more significant performance improvements than signal timing optimization alone. In general, this study confirms that proper signal management and geometric improvements at intersections play a significant role in improving traffic flow, although their effectiveness is still influenced by existing capacity limitations and peak hour traffic conditions.

CONCLUSIONS

This study shows that optimizing signalized intersection performance using the 2023 PKJI and the Webster method, as well as a combined scenario, can improve traffic performance while reducing motor vehicle emissions at Klangon Intersection 3, Sedayu Intersection 4, and Pedes Intersection 4. The analysis results show that the Webster method can significantly reduce delays and queue lengths, although the degree of saturation tends to increase slightly because the geometric capacity of the intersection remains unchanged. Meanwhile, the combined scenario that includes phase changes, geometric widening, and cycle time adjustments provides the most optimal results with a delay reduction of up to 66.29 percent and a consistent reduction in emissions for all types of pollutants due to reduced vehicle idle time. These findings confirm that appropriate signal settings and geometric improvements at intersections play a crucial role in increasing intersection operational efficiency and reducing the environmental impact of traffic activities.

However, this study has limitations because the emission analysis is only based on idle conditions with an aggregate model approach, and the data used is limited to peak hour conditions, so it does not fully represent variations in daily traffic conditions. In addition, external factors such as weather, driver behavior, and variations in vehicle composition have not been fully included in the analysis model. Therefore, further research is recommended to use a microsimulation approach and a more detailed emission model and consider broader temporal data to obtain more accurate and representative results. Practically, the results of this study can be a basis for local governments and related agencies in implementing traffic engineering based on signal timing optimization and geometric improvements at intersections to improve traffic flow and support air pollution control efforts in urban areas of Bantul Regency.

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