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TRAFFIC PERFORMANCE, FUEL CONSUMPTION, AND VEHICLE EMISSION ANALYSIS OF FIXED TIME AND ADAPTIVE ATSC SYSTEM
(Case Study: Pacific Intersection, Tegal City)

Edi Purwanto*, Sumardi
[1]Professional Engineer Program, Faculty of Engineering, Universitas Diponegoro, Jl. Prof. Soedarto, SH, Kampus UNDIP Tembalang, Semarang, Jawa Tengah 50275, Indonesia
[2]Department of Engineering, Faculty of Engineering, Universitas Diponegoro, Jl. Prof. Soedarto, SH, Kampus UNDIP Tembalang, Semarang, Jawa Tengah 50275, Indonesia
*edip@pktj.ac.id

ABSTRACT

Signalized intersections are critical points in urban road networks that impact not only traffic performance, but also fuel consumption and vehicle exhaust emissions. This study examines the Pacific Intersection of Tegal City that serves the North Coast (Pantura) Java traffic using analytical methods based on the Pedoman Kapasitas Jalan Indonesia (PKJI) 2023 and LAPI-ITB Model emission estimates. Three optimization scenarios were tested: Scenario 1 (cycle time optimization with existing phases), Scenario 2 (cycle time optimization with an early green 2-phase system, and without BKiJT), and Scenario 3 (cycle time optimization with an early green 3-phase system, and without BKiJT). The results show that the existing condition has a maximum Degree of Saturation (DS) of 0.90 with a delay of 33.7 seconds/pcu and CO emissions of 12,776.5 grams/hour. Scenario 2 produces the best performance with DS 0.852, delay 31.8 seconds/pcu, and is able to reduce fuel consumption costs by 3.78% and reduce CO emissions by 4.26% compared to existing conditions. The development of Scenario 2 using adaptive cycle time compared to fixed cycle time successfully reduces delays to level of service C in most of the observation period and saves fuel costs by Rp 204.478,- or 15.2% and reduces CO emissions by 6421.53 grams/l or 15.48% during peak and off-peak hours. This study proves that the APILL phase arrangement with an adaptive approach provides optimal solutions both technically and environmentally in accordance with the principles of engineering K3L.

Keywords: adaptive traffic signal; degree of saturation; delay; PKJI 2023; vehicle emissions

INTRODUCTION

Transportation is the lifeblood of the economy, but an increase in the number of vehicles not matched by infrastructure capacity often triggers congestion problems, especially in intersection areas (Doansyah et al., 2024; Markony & Siena, 2025; Subair et al., 2024). The Pacific Intersection in Tegal City is a strategic node connecting local urban traffic with the regional North Coast (Pantura) Java flow (Ali et al., 2024; Krisnanta et al., 2025). High vehicle volumes during peak hours cause long queues and significant delays (Arianta & Widyatami, 2025; Luo et al., 2022). Signalized intersections are the most critical points in urban road networks because the capacity limitations at these points greatly determine the smoothness of the entire network (Hang et al., 2025; Tamin, 2000). The efficiency of urban mobility and traffic engineering heavily depends on optimizing movements at conflict nodes such as intersections (Atmajaya et al., 2024; Mutambik, 2025).

Stop-and-go conditions and delays at intersections not only harm road users in terms of time (traffic performance) but also have negative environmental impacts (Abdolrazaghi et al., 2022; Uribe-Chavert et al., 2025). Vehicles in idling conditions (engine running while stopped) and accelerating after the green light comes on consume fuel inefficiently (Sim & Hwang, 2022; Tseng & Mai, 2025; Tunas, 2024). Incomplete combustion during these phases produces high exhaust emissions. Exhaust gases such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx) are known to be harmful to public health and contribute to the degradation of urban air quality. Therefore, modern transportation engineering needs to be

directed toward the concept of sustainable transportation by reducing greenhouse gas emissions at traffic congestion points (Azhar et al., 2024; Sari et al., 2019).
One effort to improve traffic control efficiency at intersections is the implementation of an adaptive traffic signal control system. Fixed-time traffic signal systems operate using a fixed cycle time without considering actual traffic conditions, making them less effective in reducing vehicle delays and queues under certain conditions (Duraku & Boshnjaku, 2024).

Conversely, adaptive traffic signal systems can adjust signal phases and timing based on real-time traffic conditions, potentially significantly improving intersection performance (Agrahari et al., 2024; Suartawan et al., 2024). Several previous studies have shown that signal timing optimization using the Indonesian Highway Capacity Guidelines (PKJI 2023) and traffic simulation approaches can improve intersection level of service, reduce the degree of saturation, and decrease vehicle queue lengths (Doansyah et al., 2024). However, most research still focuses solely on traffic performance parameters and has not comprehensively integrated analyses of fuel consumption and vehicle emissions (Saputra et al., 2026).

Therefore, a comparative study of traffic performance, fuel consumption, and vehicle emissions between fixed-time and adaptive ATSC systems is very important. Addressing intersection problems is insufficient if only viewed from partial traffic parameters; it needs to be integrated into analytical modeling that considers both technical and environmental aspects simultaneously. This study aims to: (1) Evaluate the existing condition of the Pacific Intersection in terms of traffic performance (degree of saturation, queue length, stop ratio, delay) and environmental aspects (fuel consumption, CO, HC, NOx, PM10, and SO2 gases); (2) Analyze and select the best scenario (Existing, Scenario 1, Scenario 2, and Scenario 3) from both traffic performance and environmental aspects; (3) Analyze the comparison between fixed-time ATSC and adaptive ATSC settings for the selected scenario based on traffic performance and environmental aspects.

METHOD

Research Location and Data

The research location is the Pacific Intersection in Tegal City, Central Java, which is a meeting point for east-west flows on the North Coast (Pantura) route with local urban traffic flows, as shown in Figure 1. This intersection was chosen because of its strategic characteristics as a distribution node for regional vehicles as well as an active commercial area.

Data Collection

Data collection was carried out in two stages. The first stage was a preliminary study in the form of an initial traffic count survey conducted on April 6, 2026, on Jalan Mayjend Sutoyo, one of the main approaches to the Pacific Intersection, for 12 hours (06.00-18.00 WIB). This preliminary survey aimed to empirically identify vehicle volume fluctuation patterns throughout the day to determine peak hour and off-peak hour periods before the main survey was conducted. Volume counting was carried out every 15 minutes from morning to afternoon, grouping vehicles by type. Based on the preliminary traffic counting results, three daily peak hour periods were identified: morning (06.15-07.15 WIB), midday (11.15-12.15 WIB), afternoon (16.30-17.30 WIB), and off-peak hour periods: morning (09.30-10.30 WIB), midday (12.15-13.15 WIB). The determination of these periods became the basis for determining the main survey timing, ensuring that the collected data truly reflected traffic flow conditions during peak hour and off-peak hour periods.

The second stage was the main survey conducted on April 16, 2026, using the Classified Traffic Movement Counting (CTMC) method, which is classified traffic movement counting. The CTMC survey was carried out simultaneously on all four approaches to the Pacific Intersection: North (Jl. Sutomo), East (Jl. Sutoyo), South (Jl. Sudibyo), and West (Jl. Sugiono), by placing trained observers at each intersection leg. Each vehicle crossing the stop line was recorded based on vehicle type classification (Motorcycle/MC, Passenger Car/PC, Medium Vehicle/MV, Large Bus/LB, and Large Truck/LT) and movement direction (left turn, straight, and right turn) in 15-minute recording intervals. The survey took place during the morning peak hour period (06.15-07.15 WIB), midday peak hour (11.15-12.15 WIB), afternoon peak hour (16.30-17.30 WIB), and two off-peak hour periods (09.30-10.30 WIB and 12.15-13.15 WIB). Simultaneously with the CTMC survey, recording of the existing ATSC timing was also carried out, including cycle time, green time distribution per approach, red time, green time, and lost time, as well as an intersection geometric inventory survey using a roll meter and walking measure to obtain approach width data, road gradient, and side friction conditions.

Traffic Performance Analysis (PKJI 2023)

Traffic performance analysis uses PKJI 2023. Vehicle volume is converted to Passenger Car Units (pcu/hour) using Passenger Car Equivalent (PCE) factors for opposed approaches (PC=1.00; MV=1.30; MC=0.40), except for LTOR using PCE factors for protected approaches (PC=1.00; MV=1.30; MC=0.15). The main formulations used include:

a. Saturation Flow:

$$J = J^0 \times FHS \times FUK \times FG \times FP \times FBKi \times FBK \tag{1}$$

b. Capacity:

$$\mathrm{C} = \mathrm{J} \times \left(\frac{\mathrm{WH}}{\mathrm{s}}\right) \tag{2}$$

c. Degree of Saturation:

$$\mathrm{DJ} = \frac{\mathrm{q}}{\mathrm{C}} \tag{3}$$

d. Queue Length:

$$PA = Nq \times \left(\frac{20}{LM}\right) \tag{4}$$

$$dengan\ Nq = Nq1 + Nq2$$

e. Stop Ratio:

$$\mathrm{RKH} = 0{,}9 \times \left(\frac{\mathrm{Nq}}{\mathrm{q} \times \mathrm{s}}\right) \times 3600 \tag{5}$$

f. Total Stop Ratio:

$$R_{KH} = \frac{(\Sigma N_{KH})}{q_{Total}} \tag{6}$$

g. Delay:

$$T = TLL + TG$$

$$di\ mana\ TLL = s \times \left[0{,}5 \times \frac{(1-RH)^2}{1-RH \times DJ}\right] + \left(Nq1 \times \frac{3600}{C}\right) \tag{7}$$

$$di\ mana\ TG = TG = (1 - RKH) \times PB \times 6 + (RKH \times 4)$$

h. Average Delay:

$$T_I = \frac{\Sigma(qxT)}{q_{Total}} \tag{8}$$

Fuel Consumption and Emission Estimation (LAPI-ITB)

Fuel consumption is calculated using the LAPI-ITB method with the equation:

$$F = 3{,}8889 \times 10^{-4} \times d \times Q \tag{9}$$

Where F is fuel consumption (liters), d is vehicle delay (seconds), and Q is traffic volume (pcu). Exhaust emissions are calculated by multiplying fuel consumption by emission factors per vehicle type (CO, HC, NOx, PM10, SO_2) based on Table 1.

Table 1.
Emission Factors by Vehicle Type Based on Fuel Consumption

Vehicle Type	CO (g/L)	HC (g/L)	Nox (g/L)	PM10 (g/L)	SO2 (g/L)
Motorcycle	143.4	60.5	2.9	2.5	0.08
Car (Gasoline)	409.8	40.9	20.5	0.1	0.3
Car (Diesel)	28.6	2	35.9	5.4	4.5
Bus	112.7	13.3	121.9	14.3	9.5
Truck	86.1	18.4	181.4	14.3	8.4

Research Scenarios

Four conditions for comparative analysis:

1) Existing condition without changes as baseline;
2) Scenario 1 – cycle time optimization using existing phase conditions (LTOR on East and West approaches and early green on West and South approaches);
3) Scenario 2 – cycle time optimization with a 2-phase system, early green phase for East and West approaches, and without LTOR;
4) Scenario 3 – cycle time optimization with a 3-phase system, early green phase for the South approach, and without LTOR.

The best scenario was then developed with a fixed cycle time approach and an adjusted (adaptive) cycle time per observation period.

RESULT AND DISCUSSION

Pacific Intersection Existing Condition

The Pacific Intersection consists of four approaches (North, East, South, West) with geometric characteristics as shown in Figure 1 and Table 1. The West approach has the largest width (7.9 m) and the North approach the smallest (6.6 m). Side friction on all approaches is classified as high due to commercial activities, on-street parking, and vehicle access in and out. The existing ATSC arrangement uses a 2-phase system with a cycle time of 104.

Table 2.
Geometric Conditions of the Pacific Intersection

Approach Code	Environment Type	Side Friction	LTOR	L (m)	LM (m)	W-LTOR (m)	LK (m)
N (North)	COM	High	No	6.6	6.6	0	6.6
E (East)	COM	High	Yes	7.6	4.1	3.5	7.6
S (South)	COM	High	No	7.2	7.2	0	7.2
W (West)	COM	High	Yes	7.9	4.4	3.5	7.9

As shown in Figure 2, the Pacific Intersection consists of four approaches with roadway widths ranging from 6.0 to 7.9 m, complemented by a 1.0 m median on the East and West approaches and 3.5 m channelized left-turn bypass lanes. These geometric features are designed to separate traffic movements, thereby improving traffic flow efficiency, reducing conflict points, and enhancing overall intersection safety and operational performance.

Existing Condition Traffic and Environmental Performance

Morning peak hour traffic volume shows that the West approach has the highest volume (1,206.9 pcu/hour) and the North approach the lowest (394.1 pcu/hour). The dominance of motorcycles affects flow characteristics, with flexible maneuvers but creating conflicts in the approach area. Based on PKJI 2023 calculations, the capacity and degree of saturation of existing conditions are shown in Table 3. The East approach has the highest DS (0.90) calculated using equation (3). The maximum queue length occurs at the East approach (156.09 m) calculated using equation (4), total intersection stop ratio (0.81) calculated using equation (6), and average delay of 33.7 seconds/pcu calculated using equation (8).

Table 3.
Capacity and Degree of Saturation of Existing Conditions (Morning Peak Hour)

Approach	DS	Stop Ratio	Queue Length (m)	Delay
North	0.55	0.813	45.2	41.18
East	0.90	0.928	156.09	39.38
South	0.72	0.833	78.3	38.58
West	0.69	0.657	65.7	21.11

Based on ables 4 and 5, the environmental aspects of the existing scenario show that total fuel consumption is 44.74 liters/hour calculated using equation (9) and CO emissions reach 12,776.5 grams/hour. This figure indicates that the existing ATSC system provides low efficiency both operationally and environmentally.

Table 4. Fuel Costs and Consumption

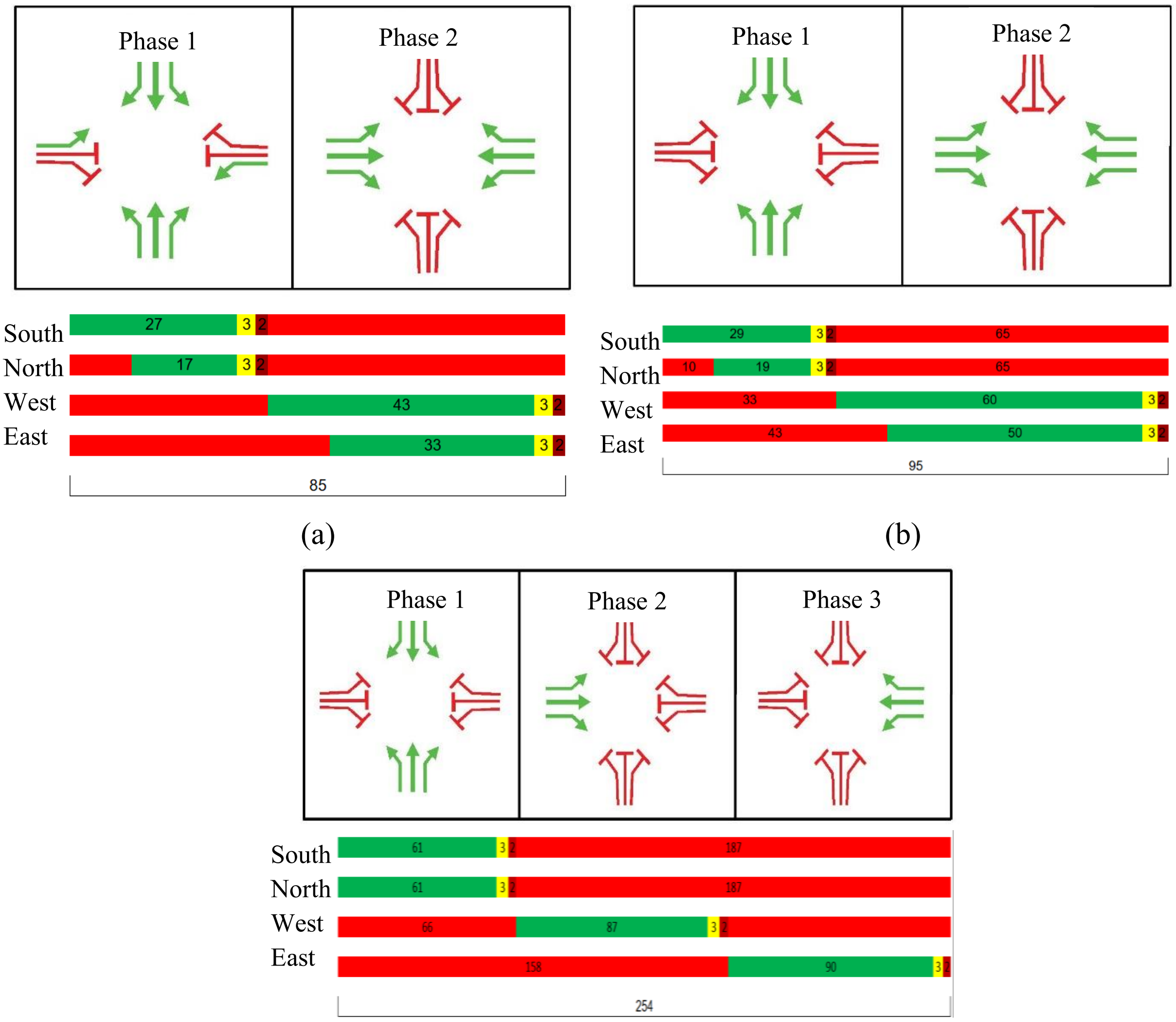
Vehicle Type	Approach	Fuel Consumption (l)
Motorcycle	North	1.4990
	East	3.1610
	South	4.24
	West	4.72
Car	North	3,67
	East	10,34
	South	6,20
	West	4,43
MV	North	1,15
	East	3,90
	South	0,68
	West	0,77
	Total Fuel (Pertalite) =	38.24
	Total Fuel (Diesel) =	6.50
	Total Fuel Consumption =	44.74
	Fuel Cost (Pertalite) =	Rp382,397.62
	Fuel Cost (Diesel) =	Rp44,189.20
	Total Fuel Consumption Cost =	Rp426,586.81

The high emission values indicate that the existing traffic condition not only causes decreased operational performance but also has a significant negative impact on environmental quality around the intersection.

Table 5.
Exhaust Emission Calculations for Each Vehicle Type

Vehicle Type	Approach	CO (g/L)	HC (g/L)	NOx (g/L)	PM10 (g/L)	SO_2 (g/L)
Motorcycle	North	214.96	90.69	4.35	3.75	0.12
	East	453.28	191.24	9.17	7.90	0.25
	South	607.70	256.39	12.29	10.59	0.34
	West	676.17	285.27	13.67	11.79	0.38
Car	North	1502.90	150.00	75.18	0.37	1.10
	East	4236.28	422.80	211.92	1.03	3.10
	South	2539.34	253.44	127.03	0.62	1.86
	West	1813.53	181.00	90.72	0.44	1.33
MV	North	129.05	15.23	139.58	16.37	10.88
	East	439.78	51.90	475.68	55.80	37.07
	South	76.94	9.08	83.22	9.76	6.49
	West	86.61	10.22	93.68	10.99	7.30
Total		12776.53	1917.25	1336.48	129.42	70.21

Comparison of Traffic Performance Between Optimization Scenarios



(a) (b)

(c)

Figure 1. (a) ATSC Signal Timing Sequence Scenario 1; (b) ATSC Signal Timing Sequence Scenario 2; (b) ATSC Signal Timing Sequence Scenario 3.

Performance comparison was conducted between the existing condition and three optimization scenarios. Existing condition without changes; Scenario 1: cycle time optimization with existing phases; Scenario 2: cycle time optimization with a 2-phase system, early green phase for the West approach, and without LTOR; and Scenario 3: cycle time optimization with a 3-phase system, early green phase for the South approach, and without LTOR. The signal timing sequences for each scenario are shown in Figure 4 for Scenario 1, Figure 5 for Scenario 2, and Figure 6 for Scenario 3.

The complete comparison of traffic performance between existing conditions, Scenario 1, Scenario 2, and Scenario 3 is presented in Table 6. The comparison of fuel consumption costs and emissions in existing conditions, Scenario 1, Scenario 2, and Scenario 3 is presented in Table 7.

Table 6.
Comparison of Traffic and Environmental Performance Between Scenarios (Morning Peak Hour)

Indicator	Existing	Sce 1	Sce 2	Sce 3
DS (Maximum)	0.90	1.05	0.852	0.955
Queue Length (Maximum)	156	158	99.8	279.9
Total Stop Ratio	0.802	0.907	0.800	0.924
Average Delay (sec/pcu)	33.7	34.5	31.8	103.1

From table 6, it can be seen that Scenario 1 failed to reduce the maximum DS (1.05) and delay (34.5 seconds/pcu), and the stop ratio also increased (0.907), indicating that vehicle conflicts in the intersection area are quite high. Scenario 3 with 3 phases and without LTOR actually showed a decrease in performance (DS decreased to 0.955 but delay jumped to 103.1 seconds/pcu) due to increased lost time per cycle and reduced efficiency of green time distribution.

Meanwhile, Scenario 2 provided the best overall performance with DS of 0.852, delay of 31.8 seconds/pcu, stop ratio of 0.800, fuel consumption of 43.01 liters/hour, and the lowest CO emissions at 12,232.05 grams. Reducing conflicts on the West and East approaches by regulating left turns following ATSC can reduce traffic conflicts from other approaches.

Table 7. Comparison of Fuel Consumption Costs and Emissions in Existing Conditions and Scenarios 1, 2, and 3

Indicator	Existing	Sce 1	Sce 2	Sce 3
Fuel Consumption (liters/hour)	44.74	47.62	43.0	139.42
CO Emissions (grams)	12,776.5	13,646.0	12,232.05	39,260.89
HC Emissions (grams)	1,917.2	1,999.13	1,852.39	6,125.56
NOx Emissions (grams)	1,336.5	1,518.66	1,268.40	3,859.85
PM10 Emissions (grams)	129.4	146.18	123.64	382.78
SO_2 Emissions (grams)	70.2	82.03	66.44	197.40

Table 7 confirms that Scenario 2 is the best from an environmental aspect, both in terms of reducing fuel consumption and reducing motor vehicle emissions.

Comparison of Fixed Time ATSC vs Adaptive ATSC (Scenario 2)

After Scenario 2 was determined as the best alternative, development was carried out using the approach of adjusting cycle time and green time for each phase according to traffic volume (Adaptive ATSC) for each observation period. In the condition where cycle time and green time for each phase are not adjusted to traffic volume (Fixed Time ATSC), all periods use a single fixed cycle time of 95 seconds. In the Adaptive ATSC condition, cycle time is recalculated using the Webster method based on actual vehicle volumes for each period. The comparison of service levels between fixed-time ATSC and adaptive ATSC is presented in

Table 8. In adaptive ATSC, average delay decreased significantly in four of the five observation periods. The afternoon peak hour showed the largest decrease (from 32.8 seconds/pcu to 24.3 seconds/pcu), thus the service level increased from D to C. The comparison of fuel consumption costs between Fixed Time ATSC and Adaptive ATSC is presented in Table 9.

Table 8.
Comparison of Service Levels between Fixed Time ATSC and Adaptive ATSC

Period	Fixed Time Delay (sec/pcu)	Fixed Time Service Level	Adaptive Delay (sec/pcu)	Adaptive Service Level	Difference (sec/pcu)
Morning Peak	31.8	D	31.8	D	0.0
Midday Peak	29.1	D	24.8	C	4.3
Afternoon Peak	32.8	D	24.3	C	8.5
Off Peak Morning	26.3	D	20.2	C	6.1
Off Peak Midday	26.1	D	19.5	C	6.6

Table 9.
Comparison of Fuel Consumption Costs between Fixed Time ATSC and Adaptive ATSC

Period	Fixed Time ATSC Fuel Cost (Rp)	Adaptive ATSC Fuel Cost (Rp)	Difference (Rp)	Savings (%)
Morning Peak Hour	Rp 410,469	Rp 410,469	Rp 0	0
Midday Peak Hour	Rp 197,817	Rp 160,151	Rp 37,666	19
Afternoon Peak Hour	Rp 255,982	Rp 217,931	Rp 38,051	14.9
Off Peak Hour Morning	Rp 185,370	Rp 137,981	Rp 47,389	25.6
Off Peak Hour Midday	Rp 295,963	Rp 214,590	Rp 81,373	27.5
TOTAL	Rp 1,345,600	Rp 1,188,511	Rp 204,478	

The comparison of vehicle emissions between fixed-time ATSC and adaptive ATSC is presented in Table 10. Adaptive ATSC is able to reduce vehicle emissions by 15% for CO, 15% for HC, 12% for NOx, 10% for PM10, and 10% for SO_2.

Table 10.
Comparison of Vehicle Emissions between Fixed Time ATSC and Adaptive ATSC

Emission Gas	APILL Type	Time					Total	Differe	Reduction (%)
		Peak Hour			Off Peak				
		Morning	Midday	Afternoon	Morning	Midday			
CO (g/L)	Fixed Time	12,232	6,247	8,068	5,860	9,063	41,470	6,422	15
	Adaptive	12,232	5,086	6,800	4,319	6,612	35,049		
HC (g/L)	Fixed Time	1,852	822	1065	776	1200	5,715	864	15
	Adaptive	1,852	658	896	570	874	4,851		
Nox (g/L)	Fixed Time	1,268	833	1078	756	965	4,901	573	12
	Adaptive	1,268	701	981	606	771	4,328		
PM10 (g/L)	Fixed Time	124	78	101	70	4	456	47	10
	Adaptive	124	65	94	58	69	409		
SO2 (g/L)	Fixed Time	66	48	62	43	50	270	27	10
	Adaptive	66	41	58	36	42	243		

The comparison between scenarios reveals complex dynamics between phase arrangement, green time distribution, and intersection performance. Scenario 2 achieves optimal balance because it combines three interventions synergistically giving right-turn flow priority reduces critical crossing conflicts without sacrificing straight flow capacity, cycle time optimization with an early green 2-phase system and without LTOR optimizes intersection performance, fuel consumption efficiency, and vehicle exhaust emissions, and full control of left turns on the East and West approaches eliminates the most influential weaving conflicts. This combination produces a maximum DS of 0.852, delay of 31.8 seconds/pcu, and CO emission reduction of 4.26% compared to existing conditions. The most significant impact is seen in the afternoon peak hour (delay reduction of 8.5 seconds/pcu, from 32.8 to 24.3 seconds/pcu) and the midday off-peak hour (reduction of 6.6 seconds/pcu). The change in service level from D to C in four of the five observation periods shows the effectiveness of the adaptive approach, consistent with theoretical studies on adaptive traffic control.

These results indicate that the adaptive ATSC system has a fundamental advantage over fixed-time ATSC systems in dealing with daily traffic volume variations. Fuel cost savings of Rp 204,478 during peak and off-peak hours, equivalent to a fuel consumption reduction of about 15.2%, are not only economically valuable but also reflect proportional emission reductions. The largest CO emission reduction (6,421.53 grams from all periods) occurs because of reduced vehicle idling duration. This proves that minimizing intersection delays is directly proportional to reducing peak emissions of CO, HC, NOx, PM10, and SO_2 gases caused by sharp acceleration.

From an implementation perspective, an adaptive ATSC approach requires investment in reprogrammable controllers or a connected traffic management center system. However, the results of this study show that the operational and environmental benefits obtained, especially improved service levels and energy savings, justify this investment. As an initial step, implementation can be carried out gradually, starting with time-of-day scheduling before switching to a full adaptive system based on vehicle detectors, as recommended by Scenario 2 with a measurable OHS&E approach.

CONCLUSION

This study produces three main conclusions. First, the existing condition of the Pacific Intersection during the morning peak hour shows unsatisfactory performance with a maximum DS of 0.90 on the East approach, average delay of 33.7 seconds/pcu (Level of Service D), and CO emissions reaching 12,776.5 grams/hour. This condition indicates the need for immediate engineering intervention to improve operational performance while reducing environmental impact. Second, of the three optimization scenarios tested, Scenario 2 (cycle time optimization with an early green 2-phase system and without LTOR) provides the best performance. This scenario produces a DS of 0.852, delay of 31.8 seconds/pcu, fuel consumption reduction of 3.78%, and CO emission reduction of 4.26% compared to existing conditions. Scenario 1 provides limited improvement, while Scenario 3 actually worsens performance due to increased lost time per cycle.

Third, the development of Scenario 2 using adaptive cycle time compared to fixed cycle time successfully reduces delays to Level of Service C in most observation periods and saves fuel costs by Rp 204,478 or 15.2% and reduces CO emissions by 6,421.53 grams or 15.48% during peak and off-peak hours. These findings prove that an adaptive ATSC system capable of adjusting cycle time to actual traffic conditions is an optimal engineering solution both technically and environmentally, aligned with OHS&E principles and engineering professional ethics. Policy makers in Tegal City are recommended to review the ATSC arrangement at the Pacific Intersection by adopting the Scenario 2 structure, accompanied by enforcement of the 'Left Turn Follow Traffic Light' rule on the West and East approaches. For further development, it is recommended to conduct a Traffic Conflict Technique survey post-implementation to record the real effectiveness of empirical accident protection, as well as implement a vehicle detector-based adaptive ATSC system to optimize energy savings and sustainable emission reduction.

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