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TRAFFIC MANAGEMENT AND ENGINEERING IMPACT ON TWO ADJACENT SIGNALIZED INTERSECTIONS - A CASE STUDY IN PONTIANAK

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Abstract — The prevalence of closely situated intersections in Pontianak City presents unique challenges, notably evident at signalized intersections along KH. Ahmad Dahlan Street. A short-term strategy for mitigating this issue involves leveraging traffic management and engineering techniques to optimize traffic flow informed by on-site evaluations. Through direct surveys conducted at both intersections, data were gathered to assess the current conditions, serving as a basis for designing a new cycle time while considering coordination theory. Using the MKJI approach, calculations were performed to optimize the performance at each intersection, with green-time adjustments facilitating coordination between them. Analysis of the existing performance revealed a saturation degree (DS) of 0.86 for the four-way intersection and 0.68 for the three-way intersection, slightly deviating from the MKJI requirement of DS = 0.75, signaling discomfort, and safety concerns. Notably, a queue length (QL) exceeding 200 m and delay time (DQ) surpassing the 25-second green cycle time underscored the necessity for improvements. Consequently, a new cycle time plan was devised, with a determined 95-second cycle time, 36-second offset time, and 16-second bandwidth adjustments between directions. The implementation of this new cycle time yielded improved intersection performance, as evidenced by the decreased average delay and queue length for both intersections. This case study investigates the efficacy of traffic management and engineering strategies at adjacent signalized intersections in Pontianak with the aim of analyzing their impact on alleviating congestion and enhancing traffic flow in urban settings. Employing various data collection methods, including traffic volume counts, intersection observations, and commuter surveys, this study demonstrates that optimizing signals, managing lanes, and enhancing pedestrian facilities significantly enhance traffic efficiency and safety. These findings offer invaluable insights for urban planners and policymakers by guiding the development of effective traffic management solutions to address congestion challenges in similar urban contexts.

Keywords: *traffic management, signalized intersection, intersection operation, signal optimization*

1.0 INTRODUCTION

In Pontianak, population expansion and urbanization have led to an increase in vehicle traffic, which presents a major challenge for efficient traffic engineering and management [1]. Signalized crossroads become key locations for managing traffic flow and guaranteeing road user safety in the context of urban growth [2]. On the other hand, ineffective intersection management frequently causes a number of issues, such as traffic jams, delays, and safety risks [3, 4]. In this regard, two particularly concerning crossings are located in Pontianak: the three-way intersection at Jalan KH. A Dahlan – Jalan Alianyang – Jalan KHW. Hasyim and the four-way intersection at Jalan KH. A Dahlan – Jalan Karimata – Jalan Johar. There are major problems because these crossroads are so close together where they are less than 200 meters apart. Occasionally, red lights require cars to stop at every intersection, obstructing traffic flow and creating lengthy lines between the two intersections. Other activities that happen around the crossroads are also impacted by this problem in addition to the traffic flow.

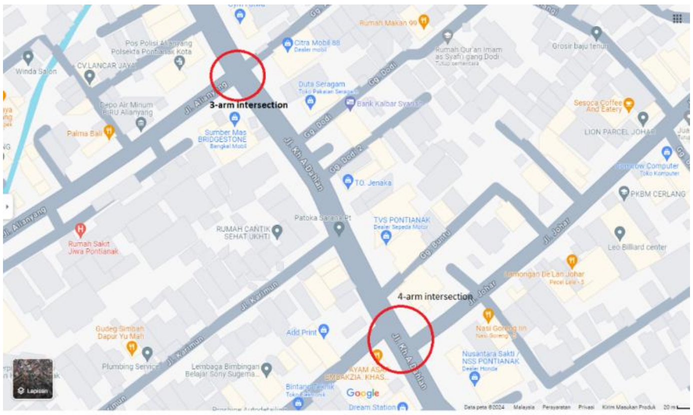


Figure 1 Observation points

These problems are caused by multiple factors. Among these are the asymmetric geometric circumstances at the crossings, drivers who disregard traffic signal restrictions, and the absence of clear information regarding traffic regulations. In addition, the diversity of land uses at the crossings increases the complexity and difficulties associated with traffic management, which eventually lowers driving safety and comfort. It is imperative that engineering interventions and traffic control be prioritized in this situation [5]. The purpose of this case study is to assess the effects of different actions taken to improve safety and traffic flow at the two crossings. It is expected that by paying more attention to proper infrastructure and more effective traffic regulation, it will be feasible to decrease delays, lessen congestion, and improve safety for all road users in the intersection area.

Additionally, previous related studies can provide valuable insights. For instance, research on the impact of adding traffic signs [6], analysis of driver behavior towards traffic regulations [7], or studies on efficient intersection geometry design [8] can serve as sources of inspiration and useful references in addressing the challenges faced in Pontianak. Therefore, collaboration between various studies and the development of integrated solutions can be key to addressing traffic issues in Pontianak more effectively. To maintain the service level of both intersections, systematic efforts in problem-solving are required, such as implementing traffic management and engineering. Evaluating the existing road infrastructure conditions, traffic volume, speed, and land use patterns around the intersections are fundamental and provide the basis for decision-making in traffic engineering and road infrastructure development [9]. Consequently, solutions can be determined using the best traffic management and engineering techniques, aiming to achieve comprehensive traffic movement efficiency with high accessibility (comfort) levels. Previous research has been conducted on these two adjacent intersections; however, previous studies only applied single strategies, such as signal coordination between the two signalized intersections, without evaluating the existing road infrastructure conditions, traffic volume, speed, and land use patterns around the intersections [10].

In the current study, several strategies were explored, which include effective traffic light arrangements, synchronization between traffic lights, and enhanced traffic management. Effective traffic light arrangements can regulate traffic flow, reduce congestion, and improve vehicle movement efficiency [11]. By exploring various possible arrangements, the research can determine the best options suitable for the needs of the respective intersections. Synchronization between traffic lights at two adjacent intersections can assist in creating smoother traffic flow, reducing queues, and minimizing delays [12]. This is an important strategy to address issues arising from the proximity of the two intersections. Traffic management enhancement is included in efforts to optimize the use of existing road infrastructure. By improving traffic management systems, including proper lane allocation and signage, conflicts between vehicles and pedestrians can be reduced, and safety at intersections can be enhanced [13].

Traffic analysis was conducted using the MKJI 1997 method [14], as MKJI 1997 (Indonesian Highway Capacity Manual) is a common and widely used standard in traffic analysis in Indonesia [15]. Many traffic experts and practitioners in Indonesia are accustomed to using this method, facilitating understanding of analysis results and communication among stakeholders. MKJI 1997 [14] was specifically developed for traffic conditions in Indonesia, making it more suitable for local conditions in Pontianak. This method considers factors such as vehicle characteristics, driver behavior, and road conditions in Indonesia, thus providing more relevant and accurate results [16]. It is also possible that previous research in Pontianak has used the MKJI 1997 [14] method, so consistent analysis with this method can enable result comparison with previous research and facilitate continuity in research and policy.

Intersections are critical areas on roads where congestion often occur due to the meeting of two or more road segments [17]. The selection of intersection types for a particular area should be based on economic considerations, traffic safety considerations, and environmental considerations (MKJI, 1997 [14]). According to MKJI 1997 [14], intersections can be categorized into two types based on their control method, namely signalized intersections and unsignalized intersections. Signalized intersections are intersections where traffic movements from each direction are controlled by traffic lights to pass through the intersection sequentially, while unsignalized intersections are intersections not controlled by traffic lights. These types of intersections are commonly found in urban areas and are suitable when traffic flow on small roads and turning movements are limited. However, if traffic flow on the main road is high, the risk of accidents for drivers on small roads is increased. In this situation, traffic lights are considered necessary.

Coordination between signalized intersections is one way to reduce delays and queues, as stated by Xu et al. [18]. According to Regulation No. 96 of 2015 from the Ministry of Transportation of the Republic of Indonesia, traffic management and engineering are a series of efforts and activities involving planning, procurement, installation, arrangement, and maintenance of road equipment facilities to realize, support, and maintain safety, security, order, and smooth flow of traffic [19]. There are three common traffic management strategies that can be combined as part of a traffic management plan. These techniques include intersection improvement, road segment management (separation of vehicle types, controlled parking on roads with specific places and times, and road widening), and area traffic control (turn restrictions, one-way road systems, and traffic light coordination) [20].

2.0 RESEARCH METHODS

This study employed a mixed-method approach, combining quantitative analysis and qualitative observation. Traffic volume calculations were conducted during peak and off-peak hours to assess traffic patterns and vehicle density. Intersection operations were observed to identify congestion points and areas. Surveys were conducted with road users to gather feedback on their experiences and perceptions regarding traffic conditions and safety measures [20]. The area that served as the focal point of observation in this study is depicted in Figures 2 and 3 below.

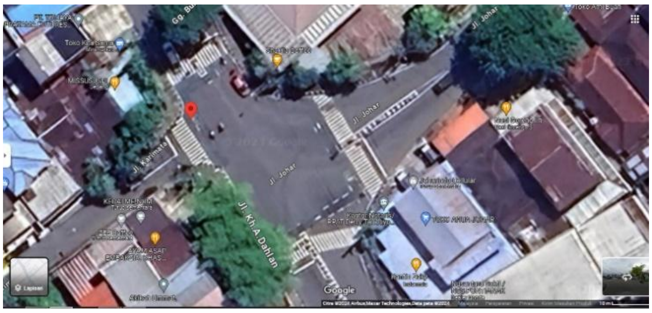


Figure 2 Map of four-way intersection

Figure 3 Map of three-way intersections

Figure 4 depicts the flowchart for analyzing studies using a mixed-method approach. The explanation of this flowchart begins with the collection of primary data. The first step is gathering primary data that includes direct information about traffic conditions and intersection operations. Quantitative analysis involves quantitatively analyzing primary data to measure traffic volume, analyze traffic patterns and density, and conduct intersection performance measurements. In addition to quantitative analysis, qualitative observations were made to understand intersection operations more deeply, including identifying congestion points, congestion areas, and other inhibiting factors. Regression and correlation analysis were conducted to identify relationships between related variables, such as the relationship between traffic volume and delays. Integrating data and findings involves combining all primary data, secondary data, and analysis results to draw main conclusions and make appropriate recommendations. The final step is to use the results to formulate relevant policies and follow-up plans.

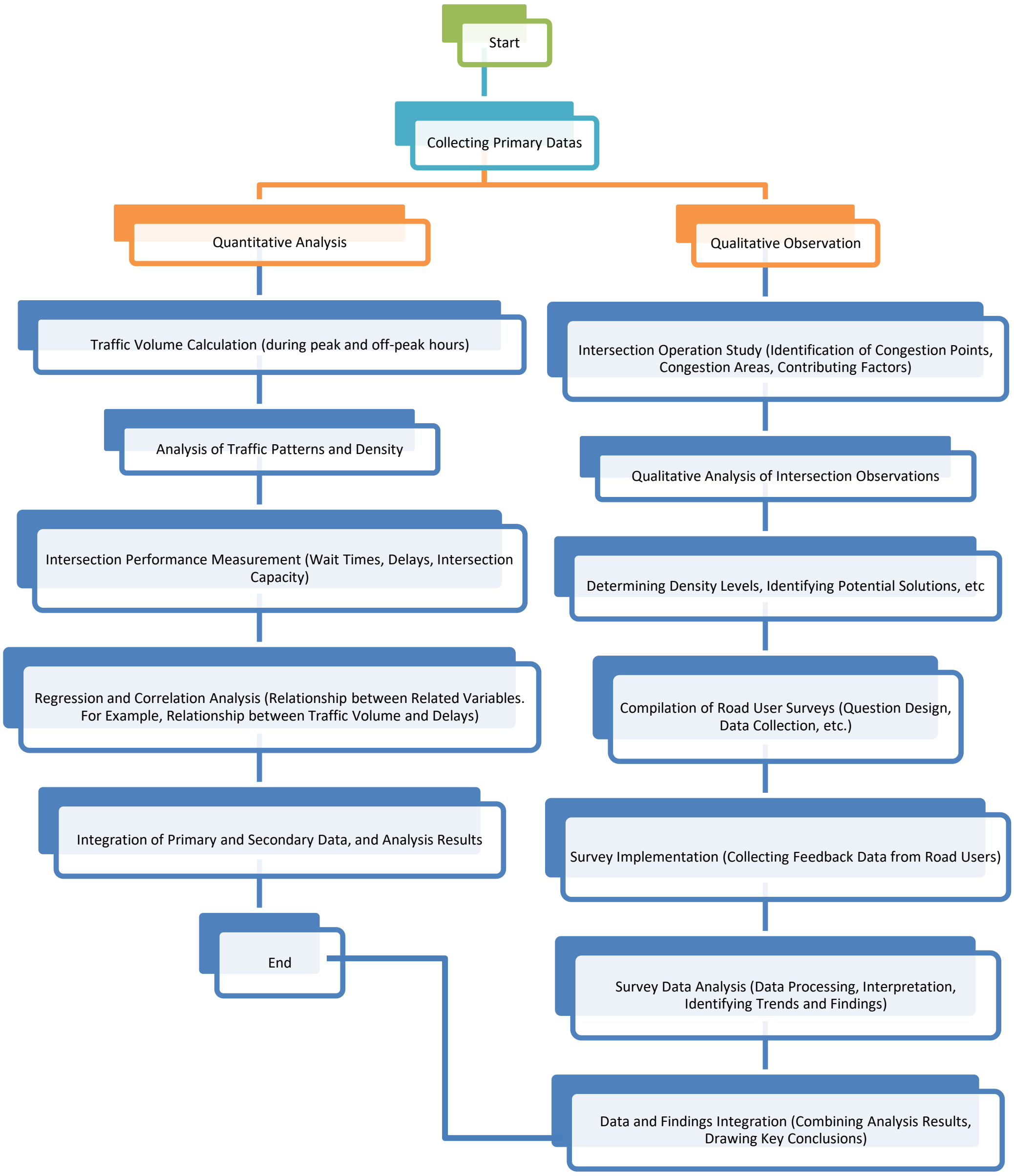


Figure 4 Flowchart of research

2.1. Traffic Volume Calculations

Calculating traffic volume is a crucial step in traffic analysis and transportation planning [21]. There are several steps used to calculate traffic volume. Firstly, the selection of observation locations is critical; these should accurately represent the traffic characteristics of the area under study. Strategic placement ensures an accurate depiction of traffic volume. Secondly, determining the calculation method is crucial, aligning it with the research objectives. Methods commonly include manual counting, automatic counting devices (e.g., vehicle counters), or utilizing traffic sensor data. A representative observation timeframe is then established, typically covering a full day or specific intervals to capture varied traffic patterns. The next step is data collection, where observations are done based on the chosen method. If performing manual counting, the number of vehicles passing the observation point within a specific time frame have to be recorded. If utilizing automatic devices, proper installation and operation have to be ensured. Subsequently, the data will be validated to ensure accuracy and consistency. Then, the traffic volume data undergo analysis to compute daily averages, compare specific times, and discern trends over time. Interpreting results comes next to understand traffic patterns and density at observed locations. Finally, these calculations serve multiple purposes such as transportation planning, road performance evaluation, and policy development, requiring careful consideration of data accuracy and method suitability.

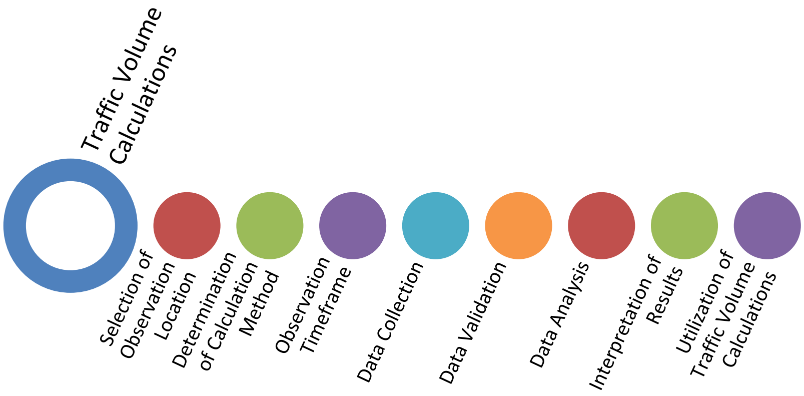


Figure 5 Steps for Traffic Volume Calculations

2.2. Survey of Road User Opinions Regarding the Comfort, Safety and Effectiveness of Intersections.

The survey includes inquiries about riders' preferences concerning particular intersection systems, such as whether road users favor traffic lights or roundabouts. Presented below are the procedural steps employed in this study for executing a survey via a straightforward questionnaire tailored for highways.

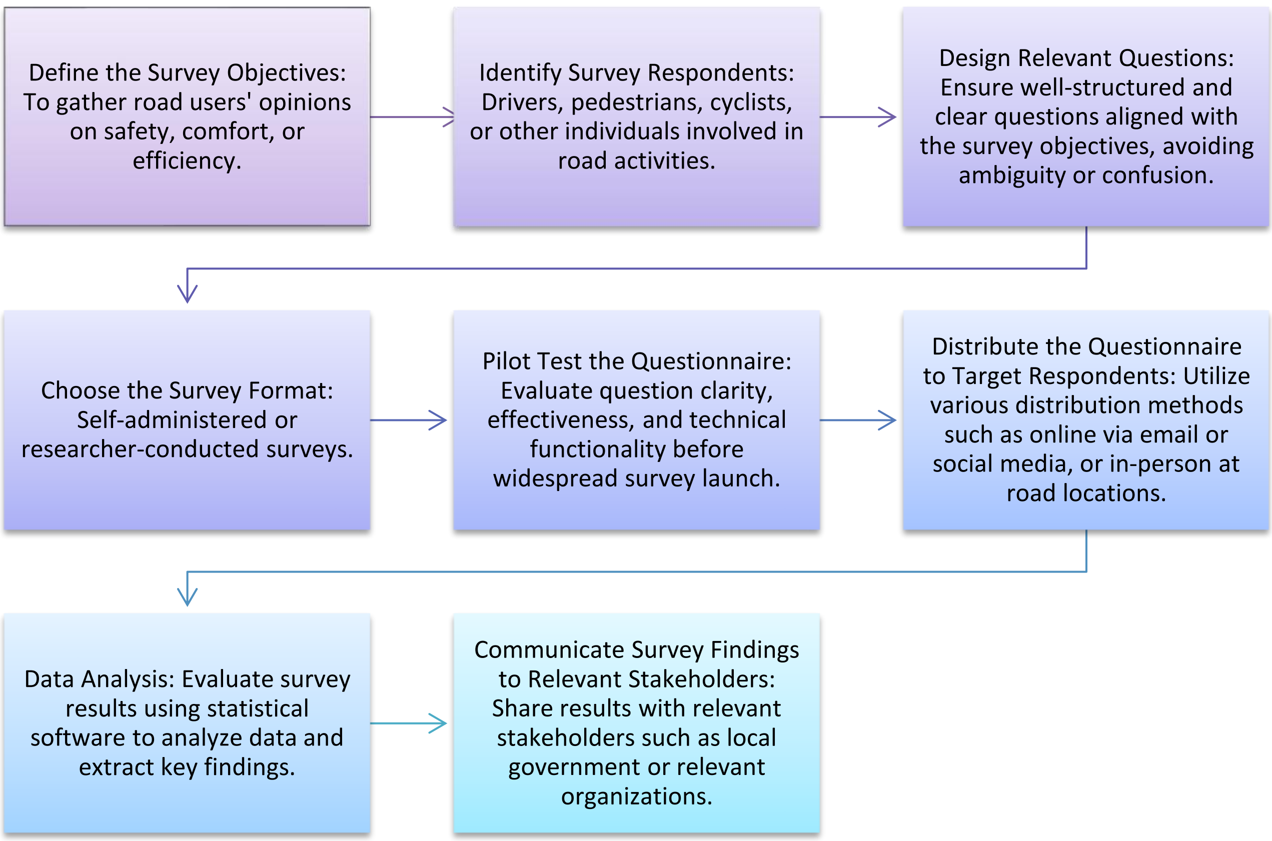


Figure 6 Procedural steps for survey

The survey results offer valuable insights for determining essential enhancements or modifications to the highway. Prioritizing safety and ethics throughout the survey process is paramount, ensuring respondent privacy and securing necessary consent [22]. Below are the survey questions designed to gather users' opinions for this study.

Table 1 Survey Form

Number	Questions	Keys	(Scores 1 – 5)				
1	How secure do you feel when crossing this intersection?	Security Level	Very Secure (5)	Secure (4)	Fairly Secure (3)	Unsafe (2)	Very Unsafe (1)
2	How comfortable do you feel using this intersection?	Comfort Level	Very Comfortable (5)	Comfortable (4)	Fairly Comfortable (3)	Uncomfortable (2)	Very Uncomfortable (1)
3	Do you feel the traffic system at this intersection is effective in managing vehicle flow?	Effectiveness Level	Very Effective (5)	Effective (4)	Fairly Effective (3)	Less Effective (2)	Very Less Effective (1)
4	Have you ever experienced an accident or incident at this intersection?	Accident Experience	Yes (1)		No (0)		
5	In your opinion, is the pedestrian crossing at this intersection safe and comfortable?	Pedestrian Crossing Satisfaction Level	Very Satisfied (5)	Satisfied (4)	Fairly Satisfied (3)	Less Satisfied (2)	Very Less Satisfied (1)
6	Do you prefer traffic lights or roundabouts at this intersection?	Intersection System Preference	Traffic Lights (5)				Roundabouts (5)
7	Do you think the traffic lights at this intersection are too long or too short?	Traffic Light Duration Perception	Too Long (5)	Fairly Long (4)	Adequate (3)	Fairly Short (2)	Too Short (1)
8	How satisfied are you with the road quality around this intersection?	Road Quality Satisfaction Level	Very Satisfied (5)	Satisfied (4)	Fairly Satisfied (3)	Less Satisfied (2)	Very Less Satisfied (1)

9	Have you ever experienced navigation difficulties or trouble finding the correct route around this intersection?	Navigation Difficulty Level	Very Easy (5)	Easy (4)	Fairly Easy (3)	Difficult (2)	Very Difficult (1)
10	Do you have any other suggestions or feedback to improve the operation of this intersection?	Willingness to Provide Feedback	Very Willing (5)	Willing (4)	Less Willing (3)	Not Willing (2)	Very Not Willing (1)
	Suggestions / Feedback						

These questions can aid in gathering users' opinions on various aspects of the intersection, including safety, comfort, effectiveness, traffic system preferences, and suggestions for improvements. By utilizing these scores, it will be possible to assign numerical weights to the responses provided by respondents, which can then be aggregated or statistically calculated to gain a better understanding of respondents' opinions and perceptions.

2.3. Quantitative Analysis

Quantitative analysis in traffic counting is crucial because it enables a deeper understanding of traffic volume, patterns, and density, which are essential for effective transportation planning [23]. It facilitates more informed decision-making regarding road planning, intersection improvements, and traffic management [24]. This analysis allows for the evaluation of intersection performance, including traffic signal efficiency, wait times, and safety levels, thereby enhancing intersection operations [25]. Moreover, it provides a robust foundation for developing effective transportation policies, aiding in designing solutions tailored to community needs.

This analysis can be conducted to assess various aspects:

- Traffic Volume: Utilizing the data, the hourly count of vehicles passing through both intersections during a defined period can be determined. Subsequently, graphs or tables illustrating the daily or weekly traffic volumes at both intersections can be generated.
- Traffic Patterns and Density: By analyzing the data, graphs or tables depicting the daily or weekly traffic volumes at both intersections can be established. This aids in identifying prevalent traffic patterns. Analyzing traffic volume data over time enables the identification of dominant traffic patterns at both intersections. Additionally, traffic density data can be used to pinpoint times when intersections experience the most congestion.
- Intersection Performance Measurement: Assessment of traffic signal cycle duration can be derived from intersection operation data. This involves evaluating whether the current traffic signal cycle durations adequately manage the existing traffic volume.
- Average Wait Time at Red Lights: Efficiency in traffic management at the intersection can be assessed by comparing the average wait time at red lights against established standards or targets.
- Number of Incidents or Accidents: This data serves as a metric to evaluate the safety level of the intersection. Determining whether the number of incidents or accidents surpasses or falls below the average for similar types of intersections is crucial.

- Availability of Pedestrian Crossing Facilities: Operational data facilitates determining the utilization rate of pedestrian crossing facilities and comparing it with the pedestrian traffic volume at the intersection. This assessment identifies any safety or comfort issues that require attention.

By conducting this analysis, the traffic volume, traffic patterns, density, and performance of the intersection can be studied quantitatively. This helps identify areas where improvements or adjustments may be needed to enhance intersection performance and safety. This quantitative analysis helps in understanding the actual performance of intersections and identifies areas where improvements or adjustments may be needed to enhance intersection performance and safety.

2.4. Qualitative Intersection Observation

Qualitative intersection observation refers to direct observations conducted to understand how an intersection operates from a qualitative standpoint [26]. It involves visual observation and analysis of various aspects that affect traffic flow and interactions among vehicles, pedestrians, and the surrounding environment. Some aspects observed in qualitative intersection observation include:

- Identification of traffic congestion points where vehicles frequently stop or move slowly.
- Monitoring of areas around the intersection prone to congestion, such as areas with sharp turns.
- Observation of external factors affecting intersection operations, such as weather, road construction, or special events.
- Evaluation of interactions between vehicles and pedestrians, including pedestrian crossing difficulties and the use of pedestrian crossing facilities.
- Review of traffic signal settings and other traffic control arrangements, including traffic signal cycle durations and pedestrian crossing times.

By conducting qualitative observations, researchers or transportation practitioners can gain a deeper understanding of intersection operational conditions, including factors influencing traffic flow and the effectiveness of traffic control systems.

2.5. Statistical Analysis

Statistical analysis refers to the process of analyzing data using statistical methods to uncover patterns, relationships, or trends within the data [27]. In the context of traffic analysis, it involves applying statistical techniques to traffic-related data to gain insights into various aspects of traffic behavior. Regression and correlation analysis are statistical methods used to examine the relationship between two or more variables. In this case, the variables of interest are traffic volume and delay at intersections. Regression analysis helps identify and quantify the relationship between a dependent variable (such as delay) and one or more independent variables (such as traffic volume). It can determine whether there is a causal relationship between the variables and predict the value of the dependent variable based on the values of the independent variables. Correlation analysis, on the other hand, measures the strength and direction of the relationship between two variables (in this case, traffic volume and delay) without necessarily implying causation. It indicates whether and how much the variables change together. Analysts can determine if there is a significant relationship between the two variables. For example, as traffic volume increases, delay at intersections also tends to increase (positive correlation), or it may discover no discernible relationship between the two variables. This information can be valuable for traffic engineers and planners in optimizing intersection design and traffic flow management.

From the data observations, the following variables are used:

Variable X: Traffic Volume (in number of vehicles per hour).
Variable Y: Delay (in seconds).

Regression analysis is used to examine if there is a linear relationship between traffic volume and delay, and correlation analysis is used to measure the strength and direction of the relationship between these two variables. Using simple linear regression method, the regression line equation can describe the relationship between traffic volume and delay.

$$Y = aX + b \tag{1}$$

Where, Y: Delay, X: Traffic Volume, a: Regression Coefficient (slope of the regression line), b: Intercept. The values of a and b determined through regression analysis

Correlation Analysis: Using Pearson correlation analysis to measure the strength and direction of the linear relationship between traffic volume and delay. The correlation value ranges from -1 to 1, where: A value of +1 indicates a perfect positive linear relationship. A value of -1 indicates a perfect negative linear relationship. A value of 0 indicates no linear relationship.

3.0 RESULTS AND DISCUSSION

3.1. Traffic Data

Vehicle volumes passing through each intersection arm can be seen in the table below.

Table 2 Traffic data for the four-way intersections

Timing	Vehicle Count	Most Common Vehicle Type	Average Speed (km/h)	Average Wait Time at Red Lights (seconds)	Traffic Density (vehicles/hour)
07.00 am – 08.00 am	1283	Motorcycle	20	30	400
08.00 am – 09.00 am	1392	Motorcycle	15	45	450
11.45 am – 00.45 pm	1901	Motorcycle	25	20	300
04.30 pm – 05.30 pm	2200	Motorcycle	18	40	600
07.00 pm – 08.00 pm	1477	Motorcycle	22	35	500

- Timing: The data was collected at five different time intervals throughout the day, ranging from morning rush hour to evening peak hours, capturing variations in traffic patterns.
- Vehicle Count: The number of vehicles passing through the intersection varied across different time intervals, with the highest count recorded during the evening peak hours (2200 vehicles) and the lowest during midday (1901 vehicles).
- Most Common Vehicle Type: Motorcycles were the predominant vehicle type observed at the intersection during all time intervals, indicating their significant presence in the area's traffic composition.
- Average Speed: The average speed of vehicles fluctuated throughout the day, ranging from 15 km/h during morning rush hour to 25 km/h during midday. However, the speeds remained relatively low across all time intervals.
- Average Wait Time at Red Lights: The average wait time at red lights varied, with the shortest wait time recorded during midday (20 seconds) and the longest during the morning rush hour (45 seconds), reflecting changes in traffic signal timing and congestion levels.
- Traffic Density: Traffic density fluctuated throughout the day, with the highest density recorded during the evening peak hours (600 vehicles/hour) and the lowest during midday (300 vehicles/hour), indicating variations in traffic volume and congestion levels.

Table 3 Traffic Data for the three-way Intersections

Timing	Vehicle Count	Most Common Vehicle Type	Average Speed (km/h)	Average Wait Time at Red Lights (seconds)	Traffic Density (vehicles/hour)
07.00 am – 08.00 am	1188	Motorcycle	18	35	360
08.00 am – 09.00 am	1339	Motorcycle	12	50	375
11.45 am – 00.45 pm	1707	Motorcycle	22	25	240
04.30 pm – 05.30 pm	2180	Motorcycle	16	45	570
07.00 pm – 08.00 pm	1582	Motorcycle	20	30	480

Table 3 presents traffic data for the three-way intersections.

- Timing: The data was collected at five different time intervals throughout the day, similar to Table 2, capturing variations in traffic patterns.
- Vehicle Count: The number of vehicles passing through the intersection varied across different time intervals, with the highest count recorded during the evening peak hours (2180 vehicles) and the lowest during the morning rush hour (1188 vehicles).
- Most Common Vehicle Type: Similar to Table 2, motorcycles were the predominant vehicle type observed at the intersection during all time intervals.
- Average Speed: The average speed of vehicles also fluctuated throughout the day, ranging from 12 km/h during morning rush hour to 22 km/h during midday.
- Average Wait Time at Red Lights: The average wait time at red lights varied, with the shortest wait time recorded during midday (25 seconds) and the longest during the morning rush hour (50 seconds), reflecting changes in traffic signal timing and congestion levels.
- Traffic Density: Traffic density fluctuated throughout the day, with the highest density recorded during the evening peak hours (570 vehicles/hour) and the lowest during midday (240 vehicles/hour), indicating variations in traffic volume and congestion levels.

Based on these results, it is determined that the peak volume at the second intersection occurs between 04:30 pm and 05:30 pm, showing the highest traffic volume compared to other hours. Therefore, the vehicle volume during these periods will be included in the calculation of the existing conditions.

Table 4 Signal timing in the four-way Intersections

Traffic Signal Cycle Duration	118 seconds		
Signal Timing	Red (seconds)	Yellow (seconds)	Green (seconds)
KH.A Dahlan Street	90	3	25
Karimata Street	90	3	25
Johar Street	90	3	25
Alianyang Street	90	3	25
Number of Incidents/Accidents (last month):	3		
Pedestrian Crossing Facilities:	Available, but rarely used		

Table 5 Signal timing in the three-way Intersections

Traffic Signal Cycle Duration	90 seconds		
Signal Timing	Red (seconds)	Yellow (seconds)	Green (seconds)
KH.A Dahlan Street	67	3	20
Alianyang Street	67	3	20
KHW. Hasyim Street	67	3	20
Number of Incidents/Accidents (last month):	2		
Pedestrian Crossing Facilities:	Available, often used		

The data above represents the actual data currently being used.

3.2. Survey Data

Below are the survey results reflecting the opinions of road users.

Table 6 The Survey Results

No	Level	Categories	%
1	Safety Level	Very Safe	15
		Safe	35
		Less Safe	40
		Unsafe	10
		Very Unsafe	0
2	Comfort level	Very Comfortable	20
		Comfortable	40
		Adequately Comfortable	30
		Less Comfortable	10
		Very Less Comfortable	0
3	Effectiveness Level	Highly Effective	25
		Effective	40
		Adequately Effective	5
		Less Effective	20
		Very Less Effective	10
4	Experienced Accidents	Yes	5
		No	95
5	Pedestrian Crossing Satisfaction Level	Very Satisfied	15
		Satisfied	15
		Adequately Satisfied	25
		Less Satisfied	35
		Very Less Satisfied	10
6	Intersection System Preference	Traffic lights	60
		Roundabouts	40
7	Perception of Traffic Light Duration	Too Long	30
		Long Enough	15
		Just Right	25
		Short Enough	20
		Too Short	10
8	Road Quality Satisfaction Level	Very Satisfied	30
		Satisfied	15
		Adequately Satisfied	25
		Less Satisfied	20
		Very Less Satisfied	10

9	Navigation Difficulty	Very Easy	15
		Easy	25
		Adequately Easy	40
		Difficult	15
		Very Difficult	5
10	Willingness to Provide Feedback	Very Willing	10
		Willing	10
		Less Willing	30
		Unwilling	40
		Very Unwilling	10

The interpretation of the data reveals the following insights:

- Safety Level: A significant portion of respondents (50%) perceived the safety level at the intersection as less than safe or unsafe, with only 50% feeling safe or very safe.
- Comfort Level: A majority of respondents (60%) felt either comfortable or very comfortable at the intersection, indicating a satisfactory level of comfort for most users.
- Effectiveness Level: While a considerable portion (45%) perceived the intersection as highly effective or effective, a significant number (30%) found it to be less effective or very less effective, suggesting room for improvement in operational efficiency.
- Experienced Accidents: Only 5% of respondents reported experiencing accidents at the intersection, indicating a relatively low incidence rate.
- Pedestrian Crossing Satisfaction Level: The satisfaction level regarding pedestrian crossings varied, with a notable portion (45%) expressing less satisfaction or very less satisfaction.
- Intersection System Preference: The majority (60%) of respondents preferred traffic lights over roundabouts, indicating a preference for the current intersection system.
- Perception of Traffic Light Duration: A significant number (30%) of respondents perceived the traffic light duration as too long, suggesting potential frustration or inconvenience with signal timing.
- Road Quality Satisfaction Level: Satisfaction with road quality was mixed, with 50% expressing satisfaction or very satisfaction, and 30% expressing less satisfaction or very less satisfaction.
- Navigation Difficulty: While a majority (55%) found navigation adequately easy or easy, a notable proportion (20%) found it difficult or very difficult, indicating potential challenges in navigation around the intersection.
- Willingness to Provide Feedback: A considerable portion (50%) of respondents expressed reluctance or unwillingness to provide feedback, indicating potential challenges in gathering user input for improvement efforts.

3.3. Geometric Condition

Figure 7 Street view of the four-way intersection

Table 7 Geometric Characteristics of the four-way Intersection

Intersection Condition	Four – arm Intersection			
	A	**B**	**C**	**D**
Street name	Karimata	KH. Ahmad Dahlan 2	Johar	KH. Ahmad Dahlan 1
Street function	Minor	Major	Minor	Major
Number of lanes	1	1	1	1
Number of paths	2	2	2	2
Width of lanes (m)	6.8	16.6	10.6	13.2
Number of directions	2	2	2	2
Width of approach (m)	4	8.2	5.4	5.8
Width of entry (m)	4	6.9	3.6	3.8
Width of left-turn lane (m)	0	1.3	1.8	2
Width of exit	2.8	8.4	5.2	7.4
Median	T	Y	Y	Y
Traffic signs	Y	Y	Y	Y

Figure 8 Street view of the three-way intersection

Table 8 Geometric Characteristics of the three-way Intersection

Intersection Condition	Three – arm Intersection		
	A	**B**	**C**
Street name	**KH. Ahmad Dahlan 3**	**KHW. Hasyim**	**Alianyang**
Street function	Major	Major	Minor
Number of lanes	1	1	1
Number of paths	2	2	2
Width of lanes (m)	11.1	12.1	8
Number of directions	2	2	2
Width of approach (m)	5.5	5.1	4
Width of entry (m)	5.5	5.1	4
Width of left-turn lane (m)	0	0	0
Width of exit	5.6	7	4
Median	T	T	T
Traffic signs	Y	Y	Y

The visual observation of the intersection environment along KH.A Dahlan Street reveals high levels of side obstacles, classified as such according to MKJI 1997. These obstacles primarily include parked vehicles near fruit stalls, electronic shops, and food stores. Additionally, vehicle movement was observed at specific locations such as the Bank KalBar Syariah Office, AKUB Campus, and BCI, Bhayangkara kindergarten, originating from local streets (Karimun Street, Gg Dodi, Gg Amal). Furthermore, pedestrians moving to and from shops and street vendors along the sidewalk also contribute to the observed conditions.

3.4. Quantitative Analysis

3.4.1. Traffic volume

Number of Vehicles Crossing the four-way Intersection:

Daily Average: (1283+1392+1901+2200+1477) / 5 = 1651 vehicles/day

Number of Vehicles Crossing the three-way Intersection:

Daily Average: (1188+1339+1707+2180+1582) / 5 = 1600 vehicles/day

Average Traffic Density at Both Intersections:

Traffic Density at the four-way Intersection: (400 + 450 + 300 + 600 + 500) / 5 = 450 vehicles/hour
Traffic Density at the three-way Intersection: (360 + 375 + 240 + 570 + 480) / 5 = 405 vehicles/hour

The relationship between traffic volume and traffic density can be observed by analyzing the average daily traffic volume and average traffic density at both the four-way and three-way intersections. For the four-way intersection, the average daily traffic volume was calculated to be 1651 vehicles per day, while the average traffic density was calculated to be 450 vehicles per hour. Similarly, for the three-way intersection, the average daily traffic volume was calculated to be 1600 vehicles per day, with an average traffic density of 405 vehicles per hour. This comparison indicates that despite the four-way intersection having a slightly higher average daily traffic volume, the traffic density was higher at the three-way intersection. This suggests that the three-way intersection may experience more congestion or slower traffic flow compared to the four-way intersection, despite handling slightly fewer vehicles on average.

3.4.2. Traffic patterns and density

Both intersections experienced peak traffic during the afternoon peak hours. The four-way intersection generally had higher traffic density compared to the three-way intersection across all time intervals. Morning rush hours also witnessed significant traffic volumes at both intersections. The midday period showed a decrease in traffic density, particularly at the three-way intersection. Overall, the traffic patterns indicate varying levels of congestion and traffic density throughout the day, with peak hours experiencing the highest traffic volumes and density.

3.4.3. Intersection performance measurement

The traffic signal cycle duration for the four-way intersection was 120 seconds, while for the three-way intersection, it was 90 seconds. Based on the operational data provided, it can be evaluated whether the existing traffic signal cycle durations are sufficient to handle the current traffic volume.

At the four-way intersection, the cycle duration was 120 seconds, which was longer compared to the cycle at the three-way intersection. This longer cycle may allow for better traffic flow management, accommodating the potentially higher volume of traffic at this intersection.

At the three-way intersection, the cycle duration of 90 seconds was shorter compared to the four-way intersection. Despite the shorter cycle, the intersection must efficiently manage traffic flow to ensure smooth movement, especially during peak hours.

The cycle durations at both intersections appear to be appropriate for managing the respective traffic volumes. However, conducting further analysis, such as observing traffic flow patterns during peak hours, may provide additional insights into the effectiveness of the signal cycle durations in handling traffic volume.

3.4.4. The average wait time at red lights

The average wait time at red lights was 34 seconds for the four-way intersection and 37 seconds for the three-way intersection. By comparing the average wait time at red lights with established standards or targets, it is possible to assess the efficiency of traffic management at the intersections.

For the four-way intersection, the average wait time of 34 seconds fell within a reasonable range for urban intersections. This suggests that the intersection efficiently managed traffic flow, minimizing delays for motorists.

With an average wait time of 37 seconds at the three-way intersection, slightly higher than the 34 seconds at the four-way intersection, it may indicate slightly less efficient traffic management. However, the wait time was still within acceptable limits for urban intersections.

Both intersections demonstrate reasonable efficiency in managing traffic flow, as indicated by their average wait times at red lights. While the three-way intersection showed a slightly higher average wait time, it remained within acceptable standards for urban intersections. Additional analysis, such as considering peak traffic periods, could provide further insights into traffic management effectiveness.

3.4.5. Accident count

At the four-way intersection, there were 3 incidents, whereas at the three-way intersection, there were 2 incidents. This data can be utilized to evaluate the safety level of the intersections by comparing the number of incidents or accidents with the average for similar types of intersections to assess their safety performance.

For the four-way intersection, with 3 incidents recorded, it suggests a moderate level of safety concerns. Further analysis is needed to determine how this count compares to the average for similar intersections in similar contexts.

For the three-way intersection, having 2 incidents indicates a relatively lower occurrence of safety issues compared to the four-way intersection. However, it is essential to benchmark this count against the average for comparable intersections to gain a comprehensive understanding of its safety performance.

The incident counts provided a preliminary indication of safety performance at each intersection. Further analysis, including consideration of factors such as traffic volume and road design, is necessary to determine whether the incident counts are above or below average for similar intersections.

3.4.6. The pedestrian crossing facilities

At the four-way intersection, the pedestrian crossing facilities were rarely used, whereas at the three-way intersection, they were frequently utilized. This data allows for understanding the usage rate of pedestrian crossing facilities and comparing it with the number of pedestrians crossing the intersection. It prompts an assessment of safety or comfort issues that may need addressing.

For the four-way intersection, the pedestrian facilities being rarely used raise concerns about their effectiveness and safety. Further investigation is necessary to ascertain why the facilities are underutilized and whether there are safety or accessibility issues hindering their usage.

As for the three-way intersection, the frequent use of pedestrian facilities suggests that it is integral to pedestrian mobility and safety at the intersection. However, a detailed examination is still necessary to ensure the facilities meet the safety standards and accommodate the needs of pedestrian effectively.

Disparities in pedestrian facility usage between the two intersections highlight potential safety and accessibility concerns. Addressing these issues may involve enhancing infrastructure, improving signage, or implementing traffic management measures to prioritize pedestrian safety and comfort.

By conducting this analysis, it becomes possible to comprehend the traffic volume, traffic patterns, density, and intersection performance quantitatively. This will aid in identifying areas where improvements or adjustments may be necessary to enhance the performance and safety of the intersection. This quantitative analysis will assist in understanding the actual performance of both intersections, as well as indicating areas where improvements or adjustments may be needed to enhance the performance and safety of the intersection.

3.5. Qualitative Intersection Observation

This data provide an overview of intersection operation conditions from a qualitative perspective, including congestion points, congestion areas, inhibiting factors, vehicle and pedestrian interactions, and evaluation of traffic signals and arrangements.

During busy hours between 07:00 - 09:00, traffic congestion occurred at the 4-way intersection, especially on lanes heading west. Vehicles tend to move slowly in that lane, leading to queues at red lights. The 3-way intersection also experienced similar congestion during the same period, especially on lanes heading north.

There were congestion areas at the four-way intersection where intersecting lanes have sharp turns. This caused difficulties for vehicles to turn, causing traffic disruption at the intersection. At the three-way intersection, congestion occurred near pedestrian crossings, often causing sudden stops for vehicles.

Inhibiting factors observed during the study include construction work around the four-way intersection, which narrowed the lanes and consequently reduced road capacity, contributing to increased congestion. Additionally, at the three-way intersection, a malfunctioning traffic light in one direction caused confusion among drivers.

Several incidents were observed where pedestrians struggled to cross at the four-way intersection due to the short green light duration for pedestrians. Some pedestrians chose to cross outside the crosswalk, posing potential accident risks.

The traffic light cycle duration at the four-way intersection appears inadequate to handle high traffic volumes. The pedestrian red light duration at the three-way intersection is too short, providing limited time for pedestrians to cross safely.

3.6. Statistical Analysis Results

The steps to obtain the results of statistical analysis are as follows:

- Data Collection: Data on traffic volume and delays at intersections were collected from direct observations or traffic sensors.
- Data Preparation: The data were then prepared for analysis, including data cleaning (e.g., removing invalid or outlier data) and organizing the data in an appropriate format.
- Regression Analysis: Through regression analysis, the relationship between the independent variable (traffic volume) and the dependent variable (delays) was evaluated. The regression equation describing the relationship between the two variables was obtained from this analysis.
- Correlation Analysis: Correlation analysis is used to measure the strength and direction of the relationship between the independent and dependent variables. In this study, the Pearson correlation coefficient was used to evaluate the linear relationship between traffic volume and delays.
- Interpretation: The results of regression and correlation analysis were analyzed to gain an understanding of the relationship between traffic volume and delays at intersections. The regression equation and correlation coefficient were used to draw conclusions about the strength and direction of the relationship between the two variables.

After conducting the analysis, the following results were obtained:

Regression Equation: $Y = 0.5X + 10$
Pearson Correlation: 0.75

From these results, it can be concluded that there was a strong positive relationship between traffic volume and delays at intersections. Each unit increase in traffic volume correlated with a 0.5-unit increase in delays, and the correlation between them was 0.75, indicating a strong relationship.

3.7. Type of Road Environment

The results of the visual observation survey of the four-way and three-way intersections on KH.Ahmad Dahlan Street - Karimata Street - Johar Street and KH.Ahmad Dahlan Street - Alianyang Street - KHW. Hasyim Street indicate that these intersections are located in a commercial area surrounded by residential areas, restaurants, shops, offices, cafes, and campuses or schools. Additionally, there are notable establishments which include the Bank KalBar Syariah Office, AKUB Campus, BCI, Bhayangkara Kindergarten, fruit stores, electronic shops, and car workshops.

The surrounding environment plays a significant role in influencing traffic at the intersections [28] mentioned above. Residential areas contribute to local traffic, especially during peak hours when residents commute to and from work or run errands. This leads to increased traffic volume and congestion around the intersections. The presence of restaurants, shops, offices, cafes, and other commercial establishments attracts both vehicular and pedestrian traffic. Customers visiting these establishments contribute to traffic congestion, especially during peak business hours. The presence of campuses or schools introduces school-related traffic, including buses, parents dropping off or picking up students, and students commuting to and from school. This leads to increased traffic volume and congestion, particularly during school hours. Overall, the combination of residential, commercial, and educational activities in the vicinity of the intersections results in varying traffic patterns throughout the day, influencing factors such as traffic volume, density, and congestion.

3.8. City Population and Land Use Data

Based on the population data of Pontianak City in the year 2023, obtained from the Population and Civil Registration Office of Pontianak City, the population is 676,096 people [29]. According to MKJI 1997 [14], a city with such a population size is classified as a medium-sized city (0.5 – 1 million inhabitants).

The population size of a city has a significant impact on traffic at intersections. A larger population generally means more vehicles on the road, leading to increased traffic volume at intersections. With a medium-sized city population of 676,096 people, the number of vehicles traveling through intersections is likely to be considerable, especially during peak hours. Higher population density often correlates with increased traffic density, particularly in urban areas. This means intersections in medium-sized cities like Pontianak may experience higher traffic density levels, especially in downtown or densely populated areas.

The size and distribution of the population influence travel patterns, including commuting routes, school zones, and commercial areas. Understanding these patterns helps transportation planners optimize traffic flow and implement effective intersection management strategies. A medium-sized city requires infrastructure that can accommodate the transportation needs of its population. This includes well-designed road networks, efficient traffic signals, pedestrian facilities, and public transportation systems to alleviate congestion at intersections. Population growth often drives urban development, leading to the construction of new residential areas, commercial centers, and recreational facilities. These developments can impact traffic patterns and necessitate adjustments to intersection design and traffic management strategies. Overall, Pontianak City as a medium-sized city which indicates a substantial demand for transportation infrastructure and services. Effective traffic management at intersections is essential to ensure smooth traffic flow, minimize congestion, and enhance road safety for residents and commuters.

3.9. Analysis of Existing Intersection Conditions

The calculation is based on the Manual of Indonesian Road Capacity (MKJI). Each parameter is calculated as follows:

- Flow Q (pcu/hours): This represents the traffic flow rate in Passenger Car Units (pcu) per hour for each approach of the intersection. It is typically obtained from traffic surveys or traffic count data.
- Capacity C (pcu/hours): This indicates the capacity of each approach of the intersection, also measured in Passenger Car Units (pcu) per hour. The capacity is determined based on the lane configurations, signal timing, geometric design, and other factors that affect traffic flow.

- Degree DS: The degree of saturation (DS) represents the ratio of traffic flow to capacity. It is calculated by dividing the flow (Q) by the capacity (C) for each approach. A degree of saturation close to 1 indicates heavy traffic congestion, while a value close to 0 indicates low congestion.
- Length QL (m): This parameter represents the queue length, measured in meters, for each approach of the intersection. It is calculated based on the flow rate (Q) and the delay (D) using the formula: $QL=Q\times D$
- Numbers (pcu/hours): This represents the number of vehicles, measured in Passenger Car Units (pcu) per hour, for each approach of the intersection. It is calculated based on the flow rate (Q) and the degree of saturation (DS) using the formula: $Numbers=Q\times DS$
- Delay D + Q: This is the total delay experienced by vehicles at the intersection, including both queue delay and delay while moving through the intersection. It is measured in seconds.
- Delay (seconds/pcu): This parameter represents the average delay per vehicle, measured in seconds per Passenger Car Unit (pcu). It is calculated by dividing the total delay (D + Q) by the number of vehicles (Numbers).

The results of the analysis of the data on existing conditions (year 2022) based on MKJI are as follows.

Table 9 Performance of the four-way Intersection (Existing)

Approach	**North Karimata**	**South Johar**	**East KH. Ahmad Dahlan 2**	**West KH. Ahmad Dahlan 1**
Flow Q (pcu /hours)	25	535	1131	436
Capacity C (pcu /hours)	29	624	1319	509
Degree DS	0.86	0.86	0.86	0.86
Length QL (m)	30	81.06	288.89	115.79
Numbers (pcu /hours)	60	518	1022	435
Delay D + Q	251.08	61.29	52.31	66.03
Delay (seconds / pcu)	59.7	59.7	59.7	59.7

Note. pcu = passenger car units

1. Flow Q (pcu/hours): 25 pcu/hour
2. Capacity C (pcu/hours): 29 pcu/hour
3. Degree DS: $DS=Q/C=25/29\approx 0.86$
4. Length QL (m): $QL=Q\times D=25\times 59.7/3600\approx 0.4146$ meters
5. Numbers (pcu/hours): $Numbers=Q\times DS=25\times 0.86\approx 21.5$ pcu/hour
6. Delay D + Q: 251.08 seconds
7. Delay (seconds/pcu): Delay=$D+Q$/Numbers=251.08/21.5≈11.67 seconds/pcu

Tabel 10 Performance of the three-way Intersection (Existing)

Approach	**North Alianyang**	**East KH. Ahmad Dahlan 2**	**West KH. Ahmad Dahlan 1**
Flow Q (pcu /hours)	251	174	770
Capacity C (pcu /hours)	373	258	1145
Degree DS	0.67	0.67	0.67
Length QL (m)	60	39.22	94.5
Numbers (pcu /hours)	78	81	57
Delay D + Q	64.45	65.37	26.36
Delay (seconds / pcu)	39.6	39.6	39.6

1. Flow (Q):
   - North Approach (Alianyang): Q=251 pcu/hour
   - East Approach (KH. Ahmad Dahlan 2): Q=174 pcu/hour
   - West Approach (KH. Ahmad Dahlan 1): Q=770 pcu/hour
2. Capacity (C):
   - North Approach (Alianyang): C=373 pcu/hour
   - East Approach (KH. Ahmad Dahlan 2): C=258 pcu/hour
   - West Approach (KH. Ahmad Dahlan 1): C=1145 pcu/hour
3. Degree of Saturation (DS):
   - North Approach (Alianyang): $DS=Q/C$=251/373≈0.67
   - East Approach (KH. Ahmad Dahlan 2): DS=174/258≈0.67
   - West Approach (KH. Ahmad Dahlan 1): DS=770/1145≈0.67
4. Length (QL):
   - North Approach (Alianyang): QL=60 meters
   - East Approach (KH. Ahmad Dahlan 2): QL=39.22 meters
   - West Approach (KH. Ahmad Dahlan 1): QL=94.5 meters
5. Numbers: This column typically represents the number of vehicles or Passenger Car Units (pcu) approaching the intersection during peak hours.
6. Delay (D + Q):
   - North Approach (Alianyang): D+Q=64.45 seconds
   - East Approach (KH. Ahmad Dahlan 2): D+Q=65.37 seconds
   - West Approach (KH. Ahmad Dahlan 1): D+Q=26.36 seconds
7. Delay per PCU:
   - North Approach (Alianyang): Delay per PCU =$D+Q/$Numbers=64.45/78 seconds/pcu
   - East Approach (KH. Ahmad Dahlan 2): Delay per PCU = 65.37/ 81 seconds/pcu
   - West Approach (KH. Ahmad Dahlan 1): Delay per PCU = 26.36/57 seconds/pcu

The evaluation results of both intersections in the existing conditions (year 2022) serve as a basis for making decisions in traffic engineering and road infrastructure development. This allows for the determination of solutions using the best traffic management and engineering techniques, aiming to achieve overall traffic movement efficiency with a high level of accessibility (comfort).

The four-way intersection had higher traffic volume compared to the three-way intersection, especially during busy hours in the morning and evening. This resulted in higher traffic density at the four-way intersection. Traffic density tends to be problematic at both intersections, especially on westbound lanes at the four-way intersection and northbound lanes at the three-way intersection. The traffic light cycle durations at both intersections need to be re-evaluated as they are not effective in managing high traffic volumes, especially during peak hours. The average wait time at red lights tends to exceed the desired standards, indicating the need for improvements in traffic light settings. Factors such as construction work around the four-way intersection and malfunctioning traffic lights at the three-way intersection because additional disruptions in traffic flow.

Based on the above analysis, several appropriate recommendations can be made. These include re-evaluating the traffic light cycle durations at both intersections and adjusting them to be more efficient in handling high traffic volumes. It is recommended that the construction work around the four-way intersection be completed to reduce disruptions in traffic flow. It is advisable to have the malfunctioning traffic lights at the three-way intersection repaired to avoid confusion and additional accident risks. The implementation of adaptive traffic light technology at both intersections should be considered to improve the efficiency of traffic light settings based on actual traffic conditions. Moreover, further evaluation should be conducted after the implementation of recommendations to monitor changes in intersection performance and ensure the effectiveness of proposed solutions. By implementing these recommendations, improvements in the performance and safety of both intersections are expected, as well as reductions in congestion and wait times for road users.

3.10. Intersection Performance Analysis

The management strategy and traffic engineering for improving intersection performance involve the selection of three alternatives. Alternative 1 utilizes the cycle time of intersection 4, and the cycle time at intersection 3 will follow the cycle time of intersection 4. Alternative 2 uses the cycle time of intersection 3, and the cycle time at intersection 4 will follow the cycle time of intersection 3. To determine the best plan, the selected plan is the one with the lowest values for saturation degree (DS), queue length (QL), and delay. Alternative 3 involves signal coordination between intersection 4 and intersection 3 using the best performance data.

The table presents the cycle time for Intersection 4 with Alternative 1. This column lists the directions or approaches to the intersection, namely North, East, South, and West, corresponding to the streets Karimata, KH. Ahmad Dahlan 3, Johar, and KH. Ahmad Dahlan 1, respectively.

1. Q (pcu): This represents the traffic flow rate (pcu - Passenger Car Units) for each approach or direction. It indicates the volume of traffic approaching the intersection from each direction.
2. S (pcu): This represents the saturation flow rate (pcu) for each approach or direction. Saturation flow rate is the maximum flow rate that can be accommodated by the intersection when traffic demand is high.
3. FR (Flow Ratio): This is the ratio of the actual flow (Q) to the saturation flow (S) for each approach. It indicates the proportion of the actual traffic flow relative to the maximum flow that can be accommodated.
4. Σ FR (Sum of Flow Ratios): This is the sum of the flow ratios for all approaches. It provides an overall measure of the traffic flow relative to the intersection's capacity.
5. PR (Penalty Ratio): This represents the penalty ratio for each approach, which is a factor used to adjust the green time for each approach based on its flow ratio. It accounts for the effect of traffic congestion on green time allocation.
6. LT1 (Lost Time 1): This is the fixed lost time, representing the time lost due to clearance intervals, pedestrian crossings, and other factors.
7. Cycle Time: This is the total duration of one cycle of traffic signal operations at the intersection. It includes the sum of green times for all approaches plus the fixed lost time.
8. Green Time: This represents the duration of the green signal for each approach during one cycle. It is the portion of the cycle time allocated for vehicles traveling in each direction to pass through the intersection

3.10.1. Intersection performance analysis alternative 1

The calculation of the new cycle time and green time is shown in the table below.

Table 11 Cycle Time for Intersection 4 - Alternative 1

Approach	four-way intersections			
	North	**East**	**South**	**West**
	Karimata	**KH. Ahmad Dahlan 3**	**Johar**	**KH. Ahmad Dahlan 1**
Q (pcu)	25	1131	535	436
S (pcu)	2273	2249	4394	2037
FR	0.09	0.15	0.10	0.16
Σ FR	0.5			
PR	0.19	0.3	0.19	0.32
LT1 (seconds)	28			
Cycle Time (seconds)	95			
Green Time (seconds)	18.05	28.5	18.05	30.4

An intersection with four approaches was considered: North, East, South, and West. The traffic flow and other parameters for each approach were as follows:

- North (Karimata Street): Q = 25 pcu, S = 2273 pcu, FR = 0.09, PR = 0.19
- East (KH. Ahmad Dahlan 3): Q = 1131 pcu, S = 2249 pcu, FR = 0.15, PR = 0.3
- South (Johar Street): Q = 535 pcu, S = 4394 pcu, FR = 0.10, PR = 0.19
- West (KH. Ahmad Dahlan 1): Q = 436 pcu, S = 2037 pcu, FR = 0.16, PR = 0.32

Cycle time calculation for this intersection:

1. Green Time Allocation: The green time for each approach was adjusted based on the penalty ratio (PR). The green time for each approach was determined by multiplying the cycle time by the PR for that approach.

- North: Green Time = Cycle Time * PR = 95 * 0.19 = 18.05 seconds
- East: Green Time = Cycle Time * PR = 95 * 0.3 = 28.5 seconds
- South: Green Time = Cycle Time * PR = 95 * 0.19 = 18.05 seconds
- West: Green Time = Cycle Time * PR = 95 * 0.32 = 30.4 seconds

2. Cycle Time Calculation: The cycle time is the sum of the green times for all approaches plus the fixed lost time (LT1).

- Total Green Time = 18.05 + 28.5 + 18.05 + 30.4 = 94 seconds (approximately)
- LT1 (Fixed Lost Time) = 28 seconds (given)
- Cycle Time = Total Green Time + LT1 = 94 + 28 = 122 seconds

The cycle time for this intersection was approximately 122 seconds.

Table 12 Cycle Time for Intersection 3 - Alternative 1

Approach	**three-way intersections**		
	North	**East**	**West**
	Alianyang	**KHW. Hasyim**	**KH. Ahmad Dahlan 2**
Q (pcu)	251	174	770
S (pcu)	3500	258	1145
FR	0.67	0.67	0.67
Σ FR		0.5	
PR	60	39.22	94.5
LT1 (seconds)		28	
Cycle Time (seconds)		95	
Green Time (seconds)	13	13	21

The results of the performance analysis for intersection 3 and intersection 4 in Alternative 1 can be seen in the table below.

Table 13 Performance of Intersection Alternative 1

Intersection condition	**four-way intersections**				**three-way intersections**		
	North	**East**	**South**	**West**	**North**	**East**	**West**
Approach	Karimata	KH. Ahmad Dahlan 2	Johar	KH. Ahmad Dahlan 1	Alianyang	KHW. Hasyim	KH. Ahmad Dahlan 3
Traffic flow Q (pcu / hours)	25	1131	535	436	251	174	770
Capacity C (pcu / hours)	32	1488	703	73	373	258	1145
Degree of saturation DS	0.75	0.74	0.66	0.76	0.67	0.67	0.67
Queue length QL (m)	30	136.4	81.06	115.79	60	39.22	94.5
CT (seconds)	95	95	95	95	95	95	95
Total Delay D + Q (seconds)	67	45	56	66	62.45	65.37	26.36
GT (seconds)	12	20	13	21	13	13	21

3.10.2 Intersection Performance Analysis Alternative 2

The calculation of the new cycle time and green time is presented in Table 14.

Table 14 Cycle Time for Alternative 2

Approach	three-way intersections			four-way intersections			
	North	East	West	North	East	South	West
	Alianyang	KHW. Hasyim	KH. Ahmad Dahlan 2	Karimata	KH. Ahmad Dahlan 3	Johar	KH. Ahmad Dahlan 1
Q (pcu)	251	174	770	25	1131	535	436
S (pcu)	3500	258	1145	2273	2249	4394	2037
FR	0.1	0.18	0.15	0.09	0.15	0.10	0.16
Σ FR		0.43				0.5	
PR	0.15	0.36	0.33	0.19	0.30	0.19	0.32
LT1 (seconds)		22				22	
Cycle Time (seconds)		90				90	
Green Time (seconds)	12	18	22	18	12	25	23

The results of the performance analysis for intersection 3 and intersection 4 in Alternative 2 can be seen in Table 15.

Table 15 Intersection Performance Alternative 2

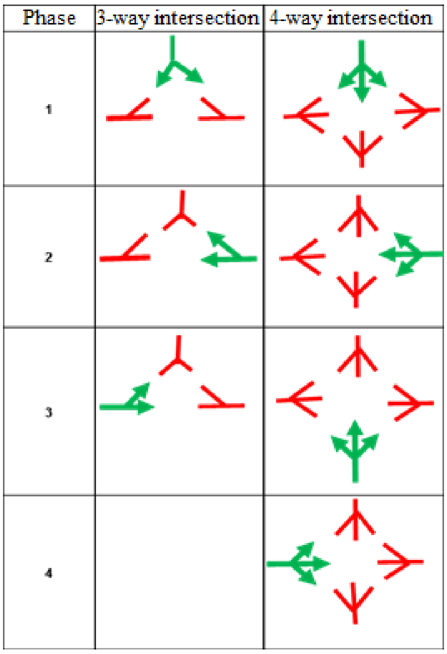
Intersection condition	**four-way intersections**				**three-way intersections**		
	North	**East**	**South**	**West**	**North**	**East**	**West**
Approach	Karimata	KH. Ahmad Dahlan 2	Johar	KH. Ahmad Dahlan 1	Alianyang	KHW. Hasyim	KH. Ahmad Dahlan 3
Traffic flow Q (pcu / hours)	25	1131	535	436	251	174	770
Capacity C (pcu / hours)	2273	249	4394	2037	3500	258	1145
Degree of saturation DS	0.76	0.78	0.66	0.76	0.68	0.67	0.67
Queue length QL (m)	30	136.4	81.06	115.79	60	39.22	94.5
CT (seconds)	90	90	90	90	90	90	90
Total Delay D + Q (seconds)	67	78	65	66	69	64.7	58
GT (seconds)	18	12	22	25	12	18	22

From the two alternatives evaluated, Alternative 1 yielded the best results as it had the smallest values in terms of saturation degree (DS), queue length (QL), and delay (DQ). Therefore, Plan 1 will be used in Alternative 3, which involves signal coordination between intersections.

3.10.3. Coordination between signalized intersections 3 and 4

The coordination plan in this research is based on the planned or average speed of 20 km/h, and the travel time between intersections is 57 seconds. This travel time was utilized as the offset time to illustrate the platoon movement trajectories in the signal coordination diagram. After obtaining the trajectories, the green time for each intersection must adjust to the next trajectory by horizontally shifting. The movement phases at both intersections can be observed in the table below.

Table 16 Intersection Phase Movements



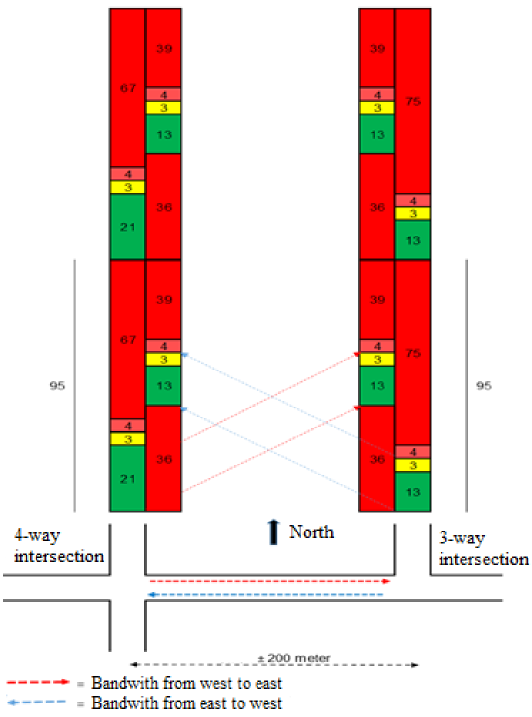


Figure 9 Coordination between both intersections

The diagram above indicates that the intersections have been coordinated. The utilized offset time was 36 seconds, resulting in a bandwidth from east to west and from west to east of 16 seconds. Analysis of traffic data revealed significant improvements in traffic flow following the implementation of various interventions. Signal optimization, including adjusting signal timings and coordination between intersections, resulted in smoother traffic progression and reduced delays. Lane management strategies, such as dedicated turn lanes and lane markings, improved traffic efficiency by minimizing conflicts and streamlining vehicle movements. Enhancements to pedestrian facilities, including crosswalks and pedestrian signals, enhanced safety and accessibility for pedestrians, reducing the risk of accidents and conflicts with vehicles.

The findings emphasize the effectiveness of targeted traffic management and engineering strategies in mitigating congestion and improving safety at signalized intersections. The success of these interventions highlights the importance of holistic approaches that consider the needs of all road users, including motorists, cyclists, and pedestrians. Additionally, the study signifies the role of data-driven decision-making in identifying problem areas and prioritizing interventions for maximum impact. This case study demonstrates the positive impact of traffic management and engineering interventions on two adjacent signalized intersections in Pontianak. By optimizing signal timings, implementing lane management strategies, and enhancing pedestrian facilities, significant improvements in traffic flow and safety were achieved. The findings provide valuable insights for urban planners and policymakers in devising effective strategies to address congestion and enhance mobility in urban environments. Continued monitoring and evaluation of traffic conditions are essential to sustain these improvements and ensure the efficient functioning of urban transportation networks.

A previous research by Wang et al. [30] also applied a signal control optimization method in their observation of adjacent intersections, utilizing an artificial intelligence algorithm to optimize this model. As a result, the signal optimization successfully reduced the delay between vehicles and pedestrians, consequently leading to shorter wait times for pedestrians and motor vehicles at intersections, thereby enhancing safety. Similarly, in the study conducted by Kaixi and Meiqi [31], which focused on alleviating traffic congestion on urban roads and analyzing traffic flow at adjacent intersections, optimization of channelization and signal timing at the intersections was facilitated by utilizing the VISSIM model for simulation purposes. This optimization effort aimed to reduce maximum queue lengths and average vehicle stopping times, thereby enabling efficient and smooth traffic flow in the area. The study provides valuable experimental insights for intersection optimization, while ensuring compatibility with real-world conditions.

4.0 CONCLUSION

From this study, it was concluded that both intersections at the current time (existing conditions) can still accommodate vehicles during peak hours, as seen from their saturation degrees (DS = 0.86 for signalized intersection 4 and DS = 0.68 for signalized intersection 3. These values were not significantly different from the MKJI requirement of DS = 0.75. However, intersections are uncomfortable and unsafe when traversing. The queue length (QL) at intersection 4 was 288 m, which was greater than the spacing between intersections of 200 m. Additionally, the delay time was 66.03 seconds, exceeding the green cycle time of 25 s, leading to queue accumulation and potential congestion, particularly during peak hours.

Three traffic engineering and management alternatives were implemented to improve the intersection performance. The first alternative plans the cycle time using the cycle time of intersection 4, and the cycle time at intersection 3 follows the cycle time of intersection 4. The results for intersection 4 are DS = 0.76, QL = 136 meters, DQ = 67 seconds, and for intersection 3: DS = 0.67, QL = 94.5 meters, DQ = 65.37 seconds. The second alternative planned the cycle time using the cycle time of Intersection 3, and the cycle time at Intersection 4 followed the cycle time of Intersection 3. The results for intersection 4 were DS = 0.76, QL = 136.4 meters, DQ = 78 seconds, and for intersection 3: DS = 0.68, QL = 94.5 meters, DQ = 69 seconds. The third alternative involved coordination between intersections using the best-performing alternative with the smallest DS, QL, and DQ values, which was the first alternative. The offset time used was 36 s, resulting in a bandwidth from east to west and from west to east of 16 s with a cycle time of 95 s. By using this new cycle time, the intersection performance improved as the queue length was reduced, and the average delay value decreased.

In future research, it is recommended to utilize artificial intelligence or application programs that facilitate simulations, enabling direct field deployment equipped with situation-reading sensors to adjust promptly to real-time conditions. This approach, combined with the optimization of channelization and signal timing methods, can enhance the adaptability and effectiveness of traffic flow management.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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