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The Performance of Roundabouts with Traffic Signals: A Case Kadipaten Intersection, Indonesia

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Abstract
Roundabouts with traffic signals at the Kadipaten intersection are one of the centers of activity in this area, with traditional markets, shops, and terminals. The rapid development in this area has caused the traffic volume at the intersection to increase, resulting in various traffic problems, including congestion and chaos. The Traffic Signaling Tool's function has yet to provide a solution to congestion and chaos, especially during rush hour. Especially with the roundabout in the middle of the intersection, which adds to the obstacle. The research method is a qualitative method, which is carried out directly or through surveys in the field that refer to IHCM 1997. This research aims to analyze the performance of traffic that occurs at the signalized roundabouts at the Kadipaten intersection. The study results show that the Duchy intersection's performance is less than optimal when using roundabouts. Interchange performance will be more optimal if the roundabout is eliminated. The decrease in intersection performance is indicated by the higher degree of saturation (DS) and delay (DT). Degree saturation at the Duchy of Interchange is currently 1.54, with the highest delay time reaching 392 seconds.

Keywords: Intersection, IHCM 1997, Roundabout, Traffic signal.

1. Introduction

Transportation problems are a severe problem to date; not only developing countries but also developing countries are experiencing it. Several significant countries that already have good transportation facilities still have transportation problems such as congestion. Traffic congestion has become a severe problem in many cities worldwide and is a challenge that is not easy to manage (Koźlak & Wach, 2018). This is due to the imbalance between the use of private vehicles and public transportation. The estimated private car ownership in 2035 will rise to 1.8 million because the predicted number of residents in future urban areas will be approximately 70% of the world population by 2050. The predictions are based on the current trends showing that private car ownership will keep its dominance in urban traffic (Campisi, Akgün, Ticali, & Tesoriere, 2020). Indonesia, as a developing country, certainly has the same problem. Indonesia now has a more than 230 million people, and the country's economic growth has increased transportation demand and vehicle ownership (Soehodho, 2017). This resulted in changes in people's life activities, resulting in a high volume of vehicles. This contributes to traffic congestion and chaos.

Majalengka experienced rapid economic growth, marked by several significant developments such as the BIJB Airport, Kertajati Toll Gate, bridges, and so on. So that people come to carry out activities in Majalengka. This causes problems at intersections in Majalengka. Other research has indicated that complex traffic management makes signalized intersections more prone to traffic problems. For example, around 22% of traffic delays occur at signalized intersections (Al-Turki, Ratrout, Rahman, & Assi, 2022).

Many factors contribute to problems at intersections, such as the appropriate use of traffic signaling tools.

The Kadipaten Intersection is one of the intersections with very high activity because there are several activity centers, such as markets. Therefore, traffic problems in the Duchy Intersection are apparent, such as congestion and delays in traffic movement due to improper traffic control used, such as uncoordinated traffic signaling tools. We find that the inefficiency of the traffic light stems from its inefficient use of the intersection region (Miculescu & Karaman, 2019) . The cause of congestion or problems at the Kadipaten Intersection is also found in the existence of a roundabout in the middle of a signalized intersection which is an obstacle. A type of road with high traffic volume and where two different road approaches meet and different traffic levels, the braided area is quickly closed, and roundabout safety is reduced (IHCM, 1997). Moreover, during rush hours, the condition of the Kadipaten Intersection still needs to accommodate the volume of vehicles.

Among several critical issues linked to urban mobility, a crucial one that has always affected public administrations is related to the high quantity of conflicts in ordinary two-lane roundabouts. Interventions such as lane reduction or diameter increasing have been avoided because it is necessary to find a solution that modifies geometric layout and does not require elevated expenses (Severino, Pappalardo, Curto, Trubia, & Olayode, 2021) . To achieve efficiency traffic at the Kadipaten Intersection, it is necessary to increase traffic performance at the intersection. This research aimed to determine the traffic performance of signalized roundabouts at the Kadipaten intersection. To provide solutions to problems in the Kadipaten Intersection so that national development is not hampered.

2. Literature Review

2.1. Intersection Performance Analysis

Traffic analysis is the complete process that starts from intercepting traffic data to finding relationships, patterns, anomalies, and misconfigurations, among other things, in the Internet network (Pacheco, Exposito, Gineste, Baudoin, & Aguilar, 2018). A multiobjective optimization problem (MOP) is formulated considering four measures in network traffic performance, i.e., maximizing system throughputs, minimizing traveling delays, enhancing traffic safety, and avoiding spillovers. For example, the design parameters for an intersection include turning signal type, cycle time, signal offset, and green time in each phase (Li & Sun, 2018). Therefore, performance analysis is thought of as testing something to produce something of quality within a specific time.

A signalized intersection is a highway facility that links one road segment and another (Putra & Ramanda, 2018) . For example, the Kadipaten Intersection is an intersection that connects access to Majalengka City - Sumedang City and Bandung - Cirebon City - and West Java International Airport. It is common for vehicles to experience delays at the Kadipaten Intersection because, apart from the high volume of vehicles, this intersection is also close to the center of the crowd. Not only that, the condition that can exacerbate the intersection is the non-compliance of drivers who are fighting for each other's way.

This cause of congestion must be evaluated, including improving the traffic capacity of intersections by widening the critical approaches and reducing the car travel demand by adding an exclusive lane to the existing road (Sun, Lin, Jiao, & Lu, 2020). Intersections also significantly affect the safety and capacity of the road network. So, it takes control - control at the intersection. Traffic management systems are composed of a set of applications and management tools to improve the overall traffic efficiency and safety of the transportation systems (De Souza, et al., 2017).

2.2. ***Traffic Signaling Devices***

Traffic Signal Device is a traffic control device that is commonly used at intersections. The aim is to give signals or orders to road users. It provides a convenient and economical approach to improving existing traffic light infrastructure. The control system is programmed on an intermediate hardware device capable of receiving messages from signals controller hardware and overriding traffic light indications during real-time operations (Jin, Ma, & Kosonen, 2017). Traffic problems often occur at intersections due to the increasing number of vehicles. Traffic is essential to increase the movement of the community, so the

Government feels it is vital to regulate by the times so that the rights of the community to use the streets are maintained (Karyaningsih & Rizky, 2020).

However, using *Traffic Signal Device* raises a new problem: the occurrence of a queue for each approach. This study adopts queueing theory and analytically shows that such a method is incapable of handling high demand with multiple conflicting traffic streams (Yu, Sun, Liu, & Yang, 2019). As traffic demand increases, it is vital to better manage intersections where traffic bottlenecks can cause congestion despite being monitored using a traffic signal controller which has three traditional signal colors: red indicating the “stop” sign, amber indicating the “slow down” sign and green indicating the “go” sign (Calvert & Snelder, 2018).

Intelligent traffic light control is critical for an efficient transportation system (Wei, Zheng, Yao, & Li, 2018). Unfortunately, the traffic lights used in the Kadipaten intersection still use manual operation. Therefore, there is nothing wrong with updating this traffic light by following today's trends, namely intelligent traffic light controllers that can be connected to today's technology.

2.3. Roundabout

The roundabout is one type of intersection control that is generally used in urban and out-of-town areas (Andika, Rifai, Isradi, & Prasetijo, 2022). The principle of the roundabout is to create a continuous stream of traffic without stopping, and the purpose of the roundabout plan is to ensure the safety of traffic between intersecting traffic and minimum delay (Surbakti & Iswahyudi, 2018). Using a circular traffic system, this roundabout prioritizes riders already on the roundabout.

Roundabouts without traffic signals are often used at intersections. This differs from the Kadipaten Intersection, which uses roundabouts at signalized intersections. This roundabout has many benefits, such as minimizing accidents due to the meeting of two or more currents with a relatively low-speed capacity. However, the roundabout at the intersection of the four counties is still experiencing congestion. The bottleneck appears at the entrance of the roundabout because vehicles need time to judge whether to enter the roundabout or to wait for another larger gap. Therefore, the research emphasizes that modern roundabouts have the entrance capacity (Guo, Liu, & Wang, 2019). In addition, many researchers have researched the characteristics of roundabout axles (Kang & Nakamura, 2017) & (Dabiri, Aghayan, & Hadadi, 2021). This is different from this research which examines the performance of intersections with Traffic Signal Device*s* and roundabouts.

3. Methodology

The purpose of descriptive research selection allows the author to collect data randomly, make descriptive, and interpret existing problems factually and in detail according to the data obtained (Ma'aruf, Eprilianto, & Megawati, 2021). Using interrelated field-based methods, data were collected, organized, validated, and analyzed to allow for the emergence of new insight theories theory (Freire, Waters, Rivas-Mariño, Nguyen, & Rivas, 2017). Thus, it can be interpreted that the qualitative research method is research carried out directly or from the field. However, qualitative research can involve various aspects of data combined from the results of field observations, interviews, and documentation.

This research was conducted in Majalengka District, located at the Kadipaten Intersection. The figure for the location of the Kadipaten Intersection is shown in figure 1. Traffic surveys are the means of collecting the base data from which traffic information will come. Good survey planning and management, stressing that data collection should only be undertaken after careful analysis of the problem to be investigated. The definition of specific data needs and the determination of resources available for data collection and analysis (Taylor & Bonsall, 2017). This survey will later obtain primary data, where the primary data is from field surveys that were observed and recorded. Emphasis had also been given to the primary data generation and allied aspects such as the construction of the data gathering instrument, content management, sampling, execution, testing, and refinement of the instrument for getting hold of the quality data, which ultimately determines the quality of the ultimate research (Riaz & Shahid, 2018).

Figure 1. Intersection Location

The primary data needed in this research is the type of traffic volume calculated directly in the field. This traffic volume survey takes three days: Monday, Tuesday, and Sunday. Recording of traffic flows carried out in 1 hour, where each period is paddy, afternoon, and evening. This research also needs geometric data of intersections and survey points. This data was collected by measuring directly at the Kadipaten Intersection with four survey points, and at each point, there was one surveyor.

4. Results and Discussion

The Condition of the Kadipaten Intersection has four Approach arms. This study also needs secondary data, such as population data obtained from the Central Bureau of Statistics for Majalengka Regency and the Kadipaten Intersection map. This map is obtained on Google Maps. The geometric figures of the intersections and survey points are shown in figure 2.

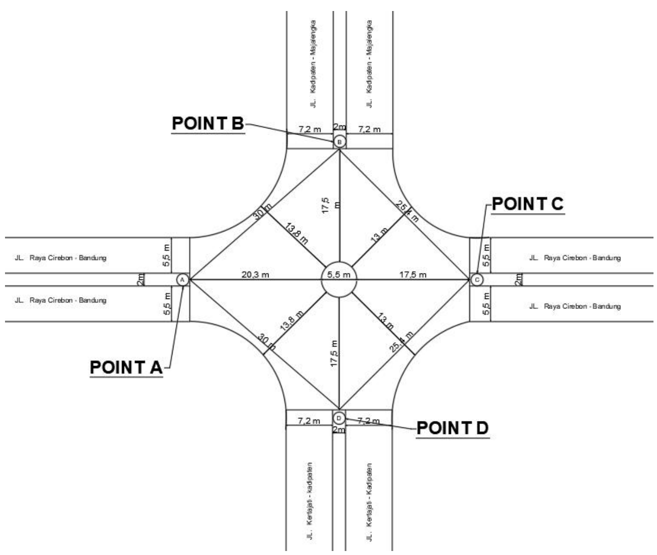

Figure 2. Intersections Geometry and Survey Points

This primary data was obtained directly through surveys in the field. The method used is using the IHCM1997 method. This research was conducted for three days by collecting data on the volume of motorcycles (MC), light vehicles (LV), and heavy vehicles (HV). The traffic volume data used is traffic flow data during peak hours. The traffic flow data at the Simpang Empat Kadipaten can be seen in the appendix below in Table 2.

Table 2. Recapitulation of Data

Intersection APILL					City: Majalengka									Perihal: 2-fase			
Traffic Flow					Intersection: Kadipaten									Periode: Jam 06.30 - 07.30			
MOTOR VEHICLE TRAFFIC FLOW																Subject: 2-Phase	
Code Pendekat	Direction	Light Vehicles (LV)			Heavy Vehicle (HV)			Motorcycle (MC)			Motor vehicle			Rasio Berbelok		current	Ratio
		protected emp = 1.0			protected emp = 1.3			protected emp = 0.2			Total						
		Challenged emp = 1.0			Challenged emp = 1.3			Challenged emp = 0.2			MV					UM	UM/MV
		Vehicle/Hour	PCU/Hour		Vehicle/Hour	PCU/Hour		Vehicle/Hour	PCU/Hour		Vehicle/Hour	PCU/Hour		PLT	PRT	Vehicle/Hour	Rms
			protected	Challenged		protected	Challenged		protected	Challenged		protected	Challenged	(%)	(%)		
Nort	LT/LTOR	152		152	12		15.6	504		201.6	668		369.2	58.2		25	
	ST	76		76	28		36.4	276		110.4	380		222.8			10	
	RT	12		12	4		5.2	64		25.6	80		42.8		6.7	21	
	TOTAL	**240**		**240**	**44**		**57.2**	**844**		**337.6**	**1128**		**634.8**			**56**	**0.05**
South	LT/LTOR	80		80	44		57.2	56		22.4	180		159.6	24.9		17	
	ST	112		112	104		135.2	180		72	398		319.2			9	
	RT	80		80	12		15.6	164		65.6	256		161.2		25.2	13	
	TOTAL	**272**		**272**	**160**		**208**	**400**		**160**	**832**		**640**			**39**	**0.05**
East	LT/LTOR	44		44	4		5.2	136		54.4	184		103.6	15.8		13	
	ST	176		176	12		15.6	388		155.2	576		346.8			19	
	RT	120		120	52		67.6	48		19.2	220		206.8		31.5	14	
	TOTAL	**340**		**340**	**68**		**88.4**	**572**		**228.8**	**980**		**667.2**			**46**	**0.05**
West	LT/LTOR	72		72	44		57.2	172		68.8	228		198	33.1		13	
	ST	68		68	16		20.8	304		121.6	388	400	210.4			20	
	RT	72		72	8		10.4	268		107.2	348		189.6		31.7	15	
	TOTAL	**212**		**212**	**68**		**88.4**	**744**		**297.6**	**1024**		**598**			**48**	**0.05**

Next, do the calculation of intersection traffic flow. The equation used is formula 1 using survey data. The most significant volume calculations were obtained from field survey results for three days at each intersection arm.

$$Q = Q_{LV}\ X\ emp_{LV} + Q_{HV}\ X\ emp_{LV} + Q_{mc}\ X\ emp_{Mc} \quad (1)$$

$$Q_{TOTAL} = Q_{RT} + Q_{LT} + Q_{ST} \quad (2)$$

With the approach challenged type, each approach has a different current, including U = 634.8 PCU/hour, S = 640.0 PCU/hour, T = 657.2 PCU/hour, and B = 598.0 PCU/hour. While the saturation current at the intersection is calculated based on the ability green light to pass the vehicle or in one approach. The magnitude of a queue departure at a predetermined state is expressed in PCU/hour. Calculation of saturation current using formula (3).

$$S = S_O + S_{CS} + S_{SF} + S_G + S_P + S_{RT} + S_{LT} \quad (3)$$

In completing the calculation, an adjustment factor is needed in the form of an Approach Challenged (So). This Challenging approach was taken from the table in IHCM 1997, as seen in table 3.

Table 3. Approach Challenged (So)

Approach	Q_{RT}	Q_{RTO}	We	So
N	43	161	5,0	2120
S	161	43	5,0	2400
E	207	190	3,0	1455
W	190	207	3,0	1450

City Adjustment Factor (Fcs) from the Central Statistics Agency for Majalengka Regency that the population of Majalengka is 1.3 million (Statistics Indonesia, 2022). Based on these figures, the coefficient value for Fcs is 1.00. The Side Barrier Factor (FSF) for the environment type at the Kadipaten Intersection is a commercial road environment (COM) type. With high side barriers for the non-motorized vehicle ratio of 0.05 and the Challenged phase tie taken from the FSF in IHCM 1997, the FSF value of 0.88 was used.

The road's slope factor (FG) at the Duchy intersection is a flat road, so the gradient used is 0.

Parking Adjustment Factor (FP) The FP value for each approach is 0.8; 0.67; 0.81, and 0.81. Factor Right Turn (FRT), and the intersection legs at the Simpang Empat Duchy have medians, so FRT = 1. The factor of Left Turn (FLT) is equal to = 1. The value of S for each approach is 1492 PCU/hour; 1415 PCU/hour; 1037 PCU/hour; and 1033 PCU/hour. Based on this value, FR can be found using formula 4. The value for FR is 0.42; 0.45; 0.63; and 0.57.

$$FR = \frac{Q}{S} \quad (3)$$

Because the Simpang Empat Kadipaten uses 2 phases, the largest Frcrit is taken in each phase with the formula 5, so that ∑Frcrit = IFR.

$$\sum FRcrit = 0,45 + 0,63 = 1,08 \quad (5)$$

The next analysis is Traffic Signal Device Phase and Time. The first step is to calculate the Lost Time Intersection (LTI). This LTI data is obtained from survey results in the field. The LTI value for each approach is in table 3. From the calculation, the LTI value is 4 seconds.

Table 7. Lost Time Intersection

Approach	Time				Cycle Time
	Green	Yellow	Red	All Red	
N and S	35	3	27	1	66
E and W	20	3	42	1	66

Capacity (C) and degree saturation (DS) continue the series of calculations using the ICHM 1997 equation, which can be seen in Formula 6. The results of calculations with this formula can be seen in table 6.

$$(C) = S\, x \frac{gi}{c}, \quad (6)$$

The C and DS values for each approach are shown in table 8. Intersection Capacity (C).

Table 6. Capacity and degree saturation

Approach	S	Gi	Cycle Time	Capacity
N	1492	35	66	790,7
S	1415	35	66	749,9
E	1037	20	66	549,6
W	1033	20	66	547,5

Based on the data from table 6, the DS value can be obtained using formula 7. So the DS value for each approach is U = 0.80, S = 0.85, T = 1.19, and B = 1.09.

$$(DS) = Q/C \quad (7)$$

The next step is to calculate the queue length for each arm. NQ can be calculated using formula 8 – formula 11. Queue Length (NQ) obtained is 10.96 PCU; 12.24 PCUs; 68.71 PCU, and 41.39 PCU.

$$NQ = NQ1 + NQ2 \quad (8)$$

$$NQ_1 = 0,25 \, . \, C \, . \left[(DS-1) + \sqrt{((DS-1)^2 + 8 \, . \, (ds-0,5)/c)} \right] \quad (9)$$

if DS≤0,5; $NQ_1 = 0$

$$(NQ)\_2 = C.1 - GR/(1 - GR \, . \, DS) \; x \; Qin/3600 \quad (10)$$

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GR = gi/c (11)

From the degree of saturation (DS), this is obtained, the length of the queue (QL), the length of the delay (DT), and the number of stops that occur in the Duchy of Intersection. The NQ values for each approach are listed in table 7. Queue Length (QL), Delay (DT), and Stop Number.

Table 7. Queue Length (QL), Delay (DT), and Stop Number

Approach	Degree of Saturation	Queue Length (QL) (m)	*Delay (DT)*	Stop Number
N	0,80	43,84	19,34 seconds	0,84
S	0,85	48,96	24,01 seconds	0,93
E	1,19	458	389,33 seconds	5,13
W	1,09	275,93	221,28 seconds	3,39

The next step is to perform a factor analysis due to the roundabout. The environmental factor values for each approach are listed in table 8, which are affected by the roundabout.

Table 8. Roundabout factor

Approach	**Roundabout Inflow (Q-entry)**	**Braid Part**	**Current Flow (Qw)**	**Total Flow (Qtot)**
N	634,8	• A-B • B-C • C-D • D-A	• 265,6 • 222,8 • 42,8 • 0	• 634,8 • 265,6 • 42,8 • 0
S	640	• A-B • B-C • C-D • D-A	• 0 • 480,4 • 319,2 • 161,2	• 0 • 640 • 480,4 • 161,2
E	657,2	• A-B • B-C • C-D • D-A	• 215,1 • 0 • 564,5 • 354,4	• 215,5 • 0 • 657,3 • 564,5
W	598	• A-B • B-C • C-D • D-A	• 211,9 • 201,2 • 0 • 413,1	• 413,1 • 201,2 • 0 • 597,8

The A-Ba braid produces a value (QW) = 256.6 PCU/hour and a total current (Q-total) = 634.8 PCU/hour. Then the value of the braid ratio (PW) of A-B braid is PW = 692.6/1263 = 0.55. The PW value for each is 0.55; 0.82; 0.78; and 0.70. The Braided Geometric Parameters at the roundabout are 0.46; 0.51; 0.51; and 0.46. The last step is calculating DS and S for the roundabout with a signal. The formula used to find DS and C can be seen in formulas 11-16.

Capacity: $(CO) = 135 \times Ww^{1,3} \times (1+WE/Ww)^{1,5} \times (1-Pw/3)^{0,5} \times (1 + Ww/Lw)^{-1,8}$. (11)

Degree Saturation: DS = Qpcu/C. dan C = Co x Fcs x Frsu (12)

Weaving width adjustment factor: $(Ww) = 135 \times Ww^{1,3}$. Faktor We/Ww $= (1+We/Ww)^{1,5}$. (13)

Weaving Ratio Factor: $(Pw) = (1-Pw/3)^{0,5}$. (14)

Factor: $Ww/Lw = (1+Ww/Lw)^{-1,8}$. (15)

City size adjustment factor (Fcs) = 1,00. (16)

The parameter values for each braid are in table 9.

Table 9. Adjustment Factor and Capacity

Weaving Part	Ww	We/Ww	(Pw)	(Ww/Lw)	Co	Fcs	F_{RSU}	C
A-B	4094	2,68	0,9	0,50	4937,3	1	0,88	4344,8
B-C	3788	2,72	0,85	0,47	4116,2	1	0,88	3622,3
C-D	3788	2,57	0,86	0,47	3935,2	1	0,88	3462,8
D-A	4094	2,59	0,87	0,50	4267,8	1	0,88	3755,6

Analysis of the Traffic Signal Device Intersection in the roundabout can use formula 17.

$$DS = DSa + DSb \quad (17)$$

Based on formula 17 and the results of previous calculations, the DS values for each approach are obtained, as shown in table 10.

Table 10. Combination DS for intersection and roundabout with traffic signal

Approach	*DS* of the Intersection *with Traffic Signal* (DSa)	*DS* of *Roundabout with Signal* (DSb)	DS
N	0,80	0,29	1,09
S	0,85	0,30	1,15
E	1,19	0,34	1,53
W	1,09	0,35	1,44

The final step is calculating the delay time (DT) according to formula 18. The DT values for each approach are listed in table 11.

$$DT = Dta + DTr \quad (18)$$

Table 11. Combination delay time for intersection dan roundabout

Approach	DT of Intersections (DTa)	DT of Roundabout (DTr)	DT
U	19,34	2,78	22,12
S	24,01	2,80	26,81
T	389,33	2,91	392,24
B	221,28	0,35	224,22

The result of the Traffic Signal Device (DTa) intersection delay coupled with the roundabout delay (DTr), namely the delay (DT) is relatively more significant than the Traffic Signal Device (DTa) intersection delay alone. Therefore, the use of traffic signals with a roundabout combination at the intersection is not optimal and reduces road performance.

5. Conclusions

The study results show that the Duchy intersection's performance is less than optimal when using roundabouts. Interchange performance will be more optimal if the roundabout is eliminated. The decrease in intersection performance is indicated by the higher degree of saturation (DS) and delay (DT). Degree saturation at the Duchy of Interchange is currently 1.54, with the highest delay time reaching 392 seconds.

Traffic management and engineering are needed to improve this interchange's performance.

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