Research Article

Updating Unsignalized Intersection Performance: A Case Study in Indonesian Cities

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Abstract: This paper focuses on updating the performance of unsignalized intersections based on the 1997 Indonesian Highway Capacity Manual (IHCM). More than two decades since its publication, IHCM has never been updated although changes in traffic characteristics have occurred resulted from the increased number of vehicles every year. The research took place in twenty intersections in eight cities in Indonesia representing small, medium, and large cities. Updating was carried out in two stages, the first was updating the value of PCE and the second was updating the value of basic capacity and capacity adjustment factors for unsignalized intersections. The results of the first stage indicated that there were changes in the value of PCE for all types of vehicles and the results of the second stage indicated an update for the adjustment factors of approach width, left turn, right turn, and minor road flow ratio. Meanwhile, basic capacity factor; median; environmental type, side friction, and non-motorized vehicles; and delay still used equations contained in IHCM. The final results indicated that there was no significant difference between the calculated delay of the updating and the field delay so that the results of the intersection updating in the form of a new formula could be used to accurately measure the performance of unsignalized intersections for current and future traffic. The implication of this research is that this is the first attempt suggesting or considering a new formula for adjusting IHCM in accordance with the latest traffic conditions.

Keywords: Updating; Performance; Capacity; New Formula; Unsignalized Intersection; IHCM.

1. Introduction

The Indonesian Highway Capacity Manual (IHCM) was first published in 1997. Over the past two decades, IHCM has never been updated and is still used in designing, planning and analyzing traffic operations in Indonesia. Irawan et al. (2010)stated that IHCM presents more actual traffic volume in Indonesia than the US Bureau of Public Roads (BPR). However,Andriyana (2013), Munawar et al. (2019), and Magfirona et al. (2015) revealed the importance of improving the formula in IHCM in order to obtain more accurate calculation. Reasons for updating IHCM are that there has been a significant increase in the number of vehicles which results in changes in vehicle composition (Putranto & Setyarini, 2011), vehicle conflicts (Lawalata & Agah, 2011), travel patterns (Ratnasari Ramlan, Irawan, & Munawar, 2021), intersection performance (Prasetio, 2007) and driver behavior (Susilo, Joewono, & Vandebona, 2015). Therefore, it is necessary to update the formula in IHCM in order toobtain an accurate calculation of road facility performance.

This research only focuses on the performance of the unsignalized intersections contained in IHCM. Unsignalized intersections are part of the road network that often suffer disruption in the form of delays and queues (Guler & Menendez, 2016). Although the traffic volume is smaller than that of other road networks, accidents at this intersection are highly likely to occur (Goyani, Nishant, Ninad, Jain, & Arkatkar, 2019). This is resulted from motorcycles with a greater percentage than other vehicles and the ability to cross intersections quickly (da Costa, Malkhamah, & Suparma, 2018) and people managing traffic in the middle of an intersection conflict area (Ratnasari Ramlan, Irawan, & Munawar, 2020) who also play a role in the performance of unsignalized intersections.

This research aims to update the formula for the performance of unsignalized intersections based on IHCM. After the update, it is expected that the results of the performance of unsignalized intersection are obtained in accordance with field data.

Field data were collected from twenty unsignalized intersections from twelve cities in Indonesia. The field data were used to calculate which parameters needed updating. The results indicated that after updating the unsignalized intersection parameters, the calculated delay value was close to the field delay value. therefore, this article contributes todetermining the appropriate formula to be used to calculate the performance of unsignalized intersections following current and future traffic conditions.

2. Literature Review

According to IHCM (Direktorat Jenderal Bina Marga, 1997), the performance of unsignalized intersections consists of capacity and delay. However, in order to obtain the performance of intersections, the parameters in IHCM were updated as follows:

2.1. Passenger Car Equivalent (PCE)

PCE is a correction factor for various types of vehicles in comparison with other passenger cars in relation to their impact on traffic behavior (Direktorat Jenderal Bina Marga, 1997). First developed in the 1965 Highway Capacity Manual, the PCE assessment becomes irrelevant if applied to developing countries with heterogeneous traffic (Mehar, Chandra, & Velmurugan, 2014; Metkari, Budhkar, & Maurya, 2012). Works of literatureon estimating PCE for unsignalized intersections are still very limited. Raj et al. (2019) revealed several commonly used methods, namely Headway method (Mohan & Chandra, 2018), flow rate method (Lee, 2015), time occupancy method (Mohan & Chandra, 2018), and simulation method (Giuffrè, Grana, Marino, & Galatioto, 2016). Furthermore, Mohan and Chandra (2018) compared 3 methods for determining PCE at unsignalized intersections, namely occupancy time method, potential capacity method, and queue clearance rate method. The results of this study revealed that the occupancy time method was suitable for traffic conditions in India. On the other hand, the speed method, or commonly known as Chandra’s Method, presented a new concept for determining PCE for various types of vehicles (S Chandra, Kumar, & Sikdar, 1995), especially for motorcycles that have higher speeds than other vehicles. Cao and Sano (2012) developed this method to determine the PCE value of a motorcycle. The speed method provides the best degree of saturation value compared to the occupancy time method for determining PCE for unsignalized intersections (R Ramlan, 2020). Based on extensive previous researches above, therefore, the speed method was used to update the PCE of all types of vehiclesin this research.

2.2. Unsignalized Intersection Capacity

Intersection capacity is the ability of an intersection to allow a maximum traffic flow. According to IHCM, the total capacity for all intersection approaches is the result of the multiplication between basic capacity (Co) for certain conditions (ideal) and adjustment factors (F), by taking the effect of actual conditions on the unsignalized intersection capacity into consideration. The adjustment factor consists of approach width; median; city size; environmental type, side friction and non-motorized vehicles; left turn; right turn and minor road flow ratio. According to Direktorat Bina Jalan Kota (BINKOT) in 1993, the results of the multiple regressions conducted show that the basic capacity and adjustment factors have a significant effect on the unsignalized intersection capacity. Furthermore, Bergh and Dardak (1994) attempted to calculate the critical gap at unsignalized intersections but the obtained results were only about 2 seconds so that the gap value at the intersections was difficult to measure. accordingly, IHCM continues to use basic capacity and adjustment factors to calculate the unsignalized intersection capacity.

3. Research Methodology

This research was conducted to obtain updates on the formula for unsignalized intersection performance based on IHCM. In order to address this objective, this research was divided into several stages as follows:

3.1. Research Location

Field data in the research were collected from twenty unsignalized intersections in 12 cities/regencies in Indonesia. The eight cities represent small city (100,000 - 500,000 residents), medium city (500,000 - 1,000,000 residents) and large city (> 1,000,000 residents). Details of the research locations can be seen in Table 1.

3.2. Data Collection

The observed unsignalized intersection belongs to type-322 intersection (3 arms, 2 lanes on minor roads, and 2 lanes on major roads). Traffic flow and vehicle speed were collected during peak hours, which were 2 hours in the morning (7:00 am to 9:00 am) and 2 hours in the afternoon (3:00 pm to 5:00 pm), then the highest volume of vehicles for an hour was calculated. Vehicle types wereclassified in order to make the calculation of traffic flow easier, consisting of non-motorized (NM), motorcycle (MC), light vehicle (LV), and heavy vehicle (HV). The geometric data and vehicle volume are shown in Table 1.

Table 1. Data of the research location.

Intersection based on city size		Lane Width (m)		Volume (vehicle/h)	Traffic composition (%)			
		minor road	major road		NM	MC	LV	HV
Small City	Siliwangi-MohToha Cirebon	2	2.39	4397	0,93	83,56	14,81	0,71
	Seturan Raya-babarsari Yogyakarta	2.9	3.76	4326	0,4	83,66	15,1	0,8
	Kusumanegara-Soepomo Yogyakarta	5,7	6	7709	0,49	88,75	10,3	0,5
	Katamso-Mantigawen Lor Yogyakarta	3,5	7,8	10154	0,56	90,25	8,83	0,4
	A.M Sangadji-Pakuningratan Yogyakarta	2.9	4.5	10747	0,16	83,72	12,7	3,5
Medium City	Pleret-SitumulyoSegoroyoso Bantul	2.5	2.6	3468	0,46	89,01	9,34	1,2
	Pleret-JejeranPleret Bantul	2.5	3	5875	0,49	86,57	11,8	1,1
	Bantul-Karangnongko Bantul	2.5	3	7815	0,61	88,43	10,6	0,3
	Moh Hatta-Ahmad YaniTasikmalaya	3.2	4.69	4433	0,4	82,38	16,8	0,4
Large City	Monjali-Tirta Marta Sleman	2.25	3.85	4933	0,14	69,98	28,7	1,2
	Godean-Nusa Indah Sleman	3.5	4	5077	0,47	82,14	16,9	0,5
	Magelang Km.22-Radjiman Sleman	2,5	4.8	9538	0,26	76,42	16,3	7
	Talun-Pepe Magelang	2.5	3	1935	2,58	80,98	16,2	0,2
	Kyai Raden Santri-Ahmad dahlanMagelang	1.9	2.1	8590	0,69	89,52	9,56	0,2
	Magelang-Wonosari	3	6	9672	0,39	81,32	14,8	3,5
	Lanto Dg. Pasewang-Rusa Makassar	3.1	3.5	4646	0,9	85,21	13,1	0,8
	Sakti Lubis-STM Medan	3	3.2	4984	0,7	84,27	14,1	0,9
	P. Dipenogoro-L. Soeprapto Semarang	6.8	11.5	5142	0,6	84,69	13,8	0,9
	Dara Suko-CemengKalangSidoardjo	2.2	2.4	5523	0,7	83,32	14,4	1,6
	R.A.A Martanegara-Maskubambang Bandung	2.2	2.2	4811	0,4	85,84	13,1	0,1

Based on Table 1, it can be seen that the highest volume of intersection was 10,154 vehicles/hour, and the lowest volume of intersection was 1935 vehicles/hour. The difference between the two was very large because the most congested intersection was located in a commercial area (shopping center) so that at peak hours the traffic conditions werevery busy with vehicles, while the other intersections were located in residential areas. This data also suggested is that the average percentage of motorcycle (MC) for all intersections was dominant (84%) compared to LV (14%), HV (1.3%), and NM (0.6%).

3.3. Data Analysis

The process of updating the performance of the unsignalized intersection was conducted through 2 stages. The first stage was updating the PCE value for all types of vehicles. The PCE value in IHCM is 0.5 for motorcycles, 1 for light vehicles, and 1.3 for heavy vehicles. Meanwhile, non-motorized vehicles do not have a PCE value. The significant growth in the number of vehicles makes the PCE value irrelevant. For example, the PCE value for motorcycles of 0.5 is used based on the assumption that two motorcycles are equivalent to one light vehicle. Data in the field indicated that motorcycles werecurrently filling the entire road because they were able to overtake and fill gaps between vehicles. Therefore, it was necessary to recalculate the PCE value for all types of vehicles using the speed method by employing the following equation:

$$PCE_i = \frac{vc/vi}{Ac/Ai} \qquad (1)$$

where PCE is the value of passenger car equivalent for each type of vehicle; Vc isthe average speed of cars (m/s); Vi isthe average speed of type i vehicles (m/s); Ac is vehicle dimensions of the cars (m^2) while Ai isthe dimension of vehicle type i (m^2).

The second stage was updating the unsignalized intersection capacity. At this stage, basic capacity and capacity adjustment factors were tested by using the trial and error method (Högberg, 1976; Munawar, 2011; Zhou, Bliemer, Yang, & He, 2015).

The final process in this research was validation by testing the difference between the value of the delay from updating calculation with the field delay. The delay based on IHCM was calculated using equation 2 as follows:

$$D = DG + 1.0504/ (0.2742 – 0.2.42*DS) \qquad (2)$$

where Dis Delay of unsignalized intersection (sec/pcu); DG is Geometric Delay (DS <1.0 = 4); and DS is Degree of Saturation.

Field delay was obtained based on the difference between the average travel time of vehicles crossing intersections along with disruption from other vehicles and the average travel time of vehicles without disruption fromother vehicles.

4. Results

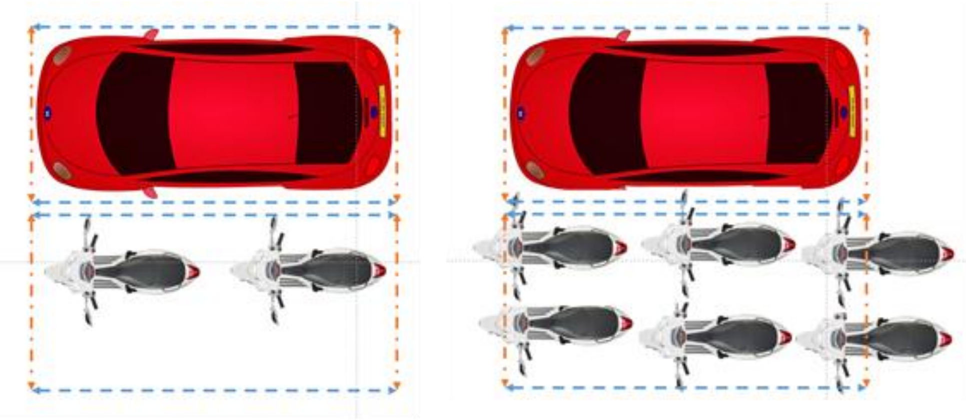
The results of the updating process for unsignalized intersection performance were divided into several parts as follows.:

4.1. Updating the PCE

The first stage of updating was updating the PCE value for all types of vehicles. This process was conducted for all types of vehicles by comparing average speed and vehicle dimensions as shown in Equation 1.

The results of the updating stage indicated the new PCE value, namely 0.45 for non-motorized vehicles; 0.17 for motorcycles; 1 for light vehicles, and 2.2 for heavy vehicles. The comparison between the traffic conditions during the making of the IHCM and the current traffic conditions is illustrated in Figure 1.

Figure 1. Comparison of the PCE value of motorcycle between IHCM condition and current condition.



a. IHCM condition b. Current condition

Figure 1 shows the difference in the ratio of vehicles between motorcycles and passenger cars or light vehicles. According to IHCM, the PCE value for motorcycles is 0.5 and the PCE value for light vehicles is 1. It can be assumed that IHCM calculates that the presence of 1 light vehicle at an unsignalized intersection is equivalent to 2 motorcycles. This is not in accordance with current traffic conditions, where the percentage of motorcycles has increased by 91% from 1997 (Central Bureau of Statistic Republic Indonesia (BPS), 2019). The result of updating the PCE value of motorcycles is 0.17 and the PCE value of light vehicles is still 1. This means that one light vehicle is equivalent to 5-6 motorcycles. This condition is possible because motorcycles are able to fill gaps between other vehicles and able to cluster when entering unsignalized intersections (R Ramlan, 2020). Another difference in PCE values also occurs for non-motorized vehicles and heavy vehicles.

4.2. Basic Capacity Update

The second updating stage was to revise the value of the basic capacity for unsignalized intersections. IHCM gives 2700 for the value of basic capacity for type-322 intersection. This means that an unsignalized intersection can accommodate a maximum total flow of 2700 vehicles for ± 1 hour in an ideal condition. The ideal conditions for the intersection consist of an average approach lane width of 2.75 meters, large-sized city, medium side friction, a ratio of 10% for right and left turns, a ratio of 20% for minor road flow, and no motorized vehicles. One sample T-Test was used toupdate the basic capacity (C_o) through a test of the difference between traffic flow and the value of basic capacity in IHCM. The result of the difference test between the calculated capacity and the basic capacity of IHCM indicated that Sig. (2-tailed) on the one sample T-Test was 0.198> 0.05. This means that the average value of the intersection capacity was the same as the basic capacity of IHCM. Furthermore, the result of the one sample T-Test indicatedthe value of T-count(1.371) <T-table(2.201), meaning that the average value of intersection capacity was the same as the basic capacity of IHCM. Thus, based on the difference test between the calculated capacity and the basic capacity of IHCM, there is no difference between the two. Therefore, the process of updating the basic capacity value still used the value of 2700 or still used the same value as that in IHCM.

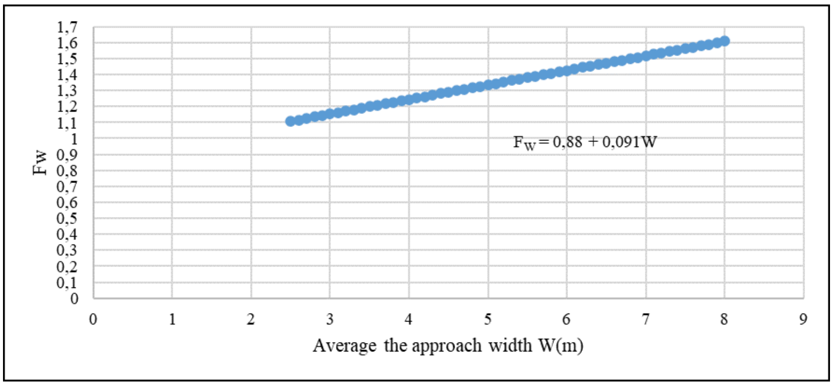
4.3. Updating approach width adjustment factor (Fw)

The third updating stage was the approach width adjustment factor. At this stage, updating was conducted using the trial and error method. The process of updating the approach width adjustment factor was conducted gradually and simultaneously for all other intersection adjustment factors. The process of updating the approach width adjustment factor stopped if the result of the calculated delay value was close to the field delay value. After updating, a new equation was obtained for determining the approach width adjustment factor as shown in Equation 3 below.

$$F_w = 0.88 + 00091.W_1 \quad (3)$$

where $F_w$is the approach width adjustment factor and $W_1$is the approach width (m). In addition to using the above equation, updating the approach width adjustment factor could also use the graph shown in Figure 2 below.

Figure 2. Updating the approach width adjustment factor



4.4. Median adjustment factor

The location of the unsignalized intersection in this research did not have a median on the main road. IHCM explains that if the intersection is without a median, it could have an adjustment factor of 1 (one). However, if the intersection has a median with a width of more than 3 meters, the adjustment factor is 1.2. In other words, an intersection without a median makes the entire intersection area for traffic flow, so that the adjustment value is one.

4.5. City size adjustment factor

According to IHCM, the composition of motorcycles for small-sized city is approximately 34.5%, medium-sized city is approximately 57% and large-sized city is approximately 41%, but the composition of motorcycles in the field ranges is more than 80% for all city sizes. Likewise, the composition of light vehicles is 10-15% and heavy vehicles are1-2% in small, medium, and large-sized cities. This is consistent with a study conducted by Putranto and Setyarini(Putranto & Setyarini, 2011) that there has been a change in vehicle composition in the IHCM data and the field data in Indonesia.

This proves that the city size factor has no effect on the number of vehicles in the city. In addition, the city size factor does not affect the behavior of motorcyclists. Susilo et al. (2015) stated that there was a similarity in driver behavior in cities in Indonesia. This is consistent with the results of field observations, that the behavior of drivers in all city sizes was relatively the same, such as not obeying rules and being aggressive when crossing intersections. Another fact was the similarity between vehicle conflicts that occurred at unsignalized intersections for all city sizes. Vehicle conflicts that commonly occur are turning movements, especially vehicles that turn right (R Ramlan, 2020). This condition is strengthened by a study conducted by Lawalata and Agah (2011) that there are similarities between vehicle conflicts at unsignalized intersections in Indonesia.

Therefore, it can be concluded that the city size factor does not affect the number of vehicles, driver behavior, movement conflicts, so that this factor can be considered as not affect the capacity of unsignalized intersections.

4.6. Adjustment factor for environmental type, side friction and non-motorized vehicles

According to IHCM, the values of the adjustment factor for environmental type, side friction, and non-motorized vehicles are based on the assumption that the effect of non-motorized vehicles on capacity is the same as light vehicles ($PCE_{UM} = 1.0$). IHCM suggests that if it is proven that the PCE_{UM} value is ≠ 1.0, then equation 4 can be used.

$$F_{RSU}\ (P_{UM}real) = F_{RSU}\ (P_{UM} = 0) \times (1 - P_{UM} \times PCE_{UM}) \quad (4)$$

Where, $F_{RSU}$is adjustment factor for road environment type, side friction, and non-motorized vehicles; $P_{UM}$is non-motorized vehicle ratio and $PCE_{UM}$is passenger car equivalent for non-motorized vehicles.

Therefore, the updating adjustment factor for environmental type, side friction, and non-motorized vehicles still used equation 4 in IHCM.

4.7. Adjustment factor for left turn, right turn and minor road flow ratio

The updating process on the adjustment factor for left turn, right turn, and minor road flow ratio was conducted gradually and simultaneously for all other intersection adjustment factors. These adjustment factors generated the following equation used for the updating:

Equation 5 is the result of updating for the adjustment factor for left turn, equation 6 is the result of updating for the adjustment factor for left turn, and equation 7 is the result of updating for the adjustment factor for minor road flow ratio.

$F_{LT} = 0.99 + (1,76 \text{ x } P_{LT})$ (5)

$F_{RT} = 1,09 - 0,922 \, P_{LT}$ (6)

$F_{MI} = 1,34 \text{ x } P_{MI}^2 -1,34 \text{ x } P_{MI} +1,34 \text{ (for } P_{MI} = 0,1\text{-}0,5)$ (7)

where F_{LT} isleft turn adjustment factor, $P_{LT}$is left turn ratio, F_{RT}isright turn adjustment factor, $P_{RT}$is right turn ratio, $F_M$isminor road current ratio adjustment factor and P_{MI}isminor road current ratio.

In addition to using the above equations, updating the adjustment factor for left turn, right turn and Minor road current ratio could use the graphs in Figure 3 to Figure 5 below.

Figure 3. Updating adjustment factor for left turn

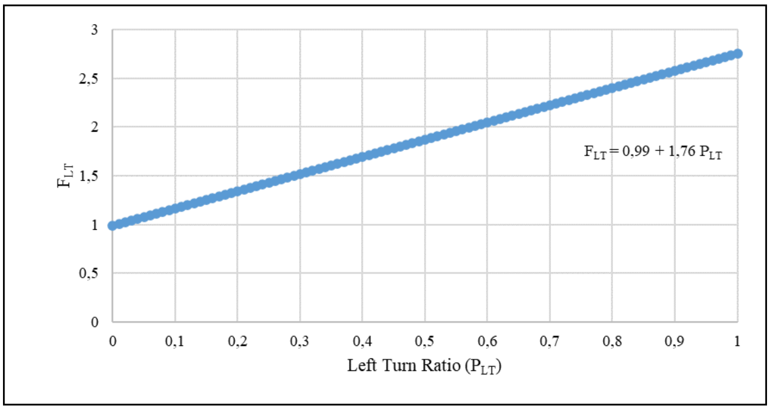


Figure 4. Updating adjustment factor for right turn.

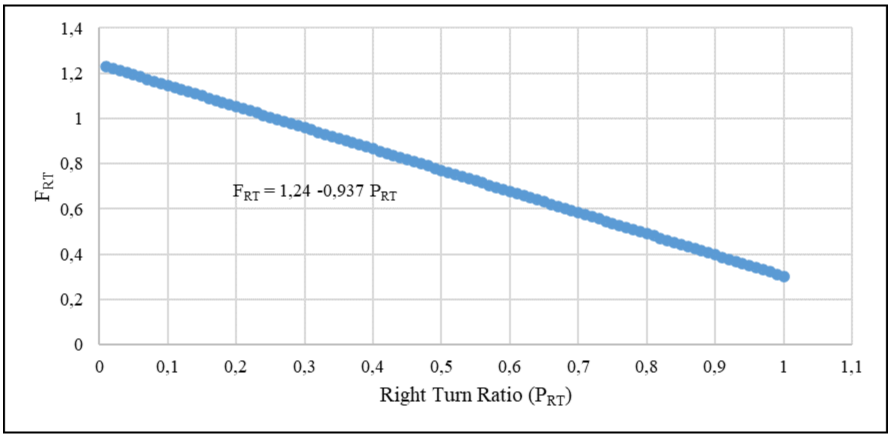
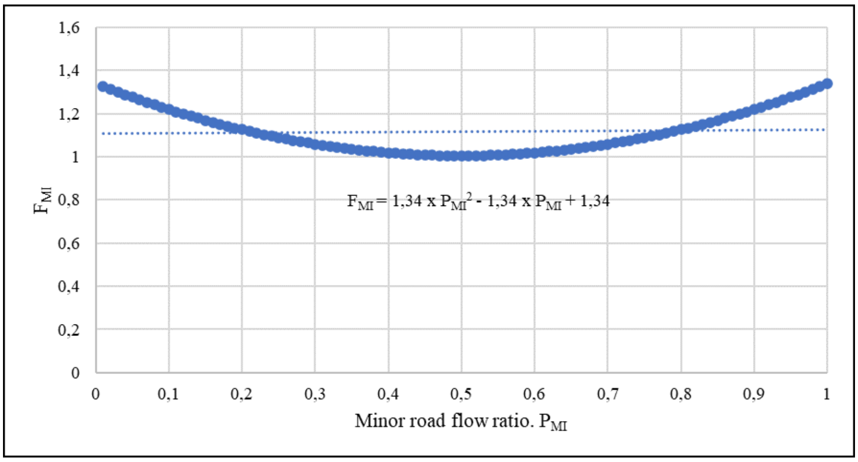


Figure 5. Updating adjustment factor for minor road flow ratio.



4.8. Data Validation

The final stage of the updating process was data validation. The validation process was conducted from the results of updating the performance formula for unsignalized intersections. Furthermore, the delay value was calculated based on equation 2. As a comparison to the result of the calculated delay using equation 2, the field delay value was calculated directly on the observation of vehicle movement. Furthermore, the difference test between the value of the updated delay and the field delay was conducted using the independent simple T-test. The test results can be seen in Table 2 below.

Table 2. Results of the independent simple T-Test between the updated delay and the field delay.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	0.001	0.972	0.196	22	0.047	0.25	1.27	-2.38	2.87
Equal variances not assumed			0.196	21.99	0.047	0.25	1.27	-2.38	2.87

The results of the Independent Sample T-Test above show the value of Sig. Levene's test of 0.972, which was greater than the required 0.05. This means that the data variance between field delay and delays of updated intersection performance was the same. In the equality of means, the Sig. (2-tailed) was 0.047, smaller than the required 0.05. therefore, as the basis for decision making in the independent sample t-test, it can be concluded that H0 was rejected and Ha was accepted. These results indicated that there was no difference between the average field delay and the delay of updated intersection performance.

Furthermore, from Table 2, it was obtained that the value of T-count was 0.196, while the data from T-table was 1.321. This shows that T-count<T-table, meaning that there was no difference between the value of field delay and delay of updated intersection performance.

The graphic method is shown in Figure 6 below can be used to find out profoundly the difference between the calculated delay and the field delay.

Figure 6. Comparison between field delay and delay in updated intersection performance.

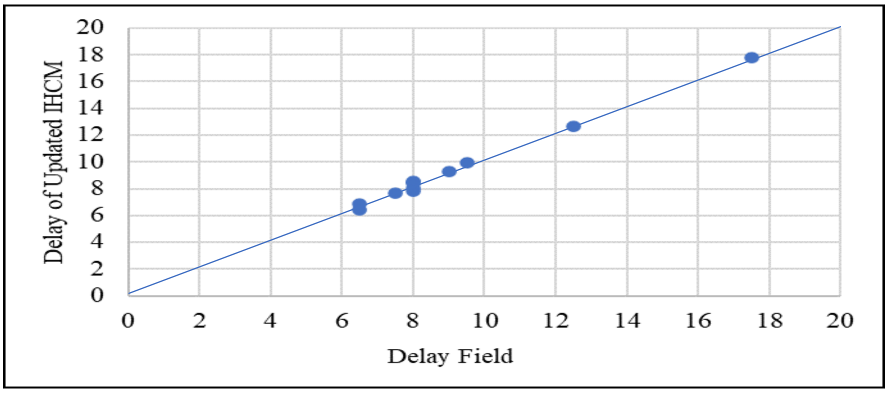


Figure 6 shows that the data plot points form a straight-line pattern between the values of the delay of updated intersection performance (x) and the field delay (y). The distribution of data that forms astraightline pattern shows that the delay value of updated intersection performance is close to the value of field delay.

The results of difference tests conducted on the values of field delay and the delay of updated intersection performance either using the Independent Sample T-Test or by means of the graphical method show that the value of the updated delay and the field delay had no difference. Therefore, the new formula obtained had fulfilled the requirements for updating the performance of unsignalized intersections. The calculation results had corresponded to the field data so that it could be said that it indicated accurate results.

The final results of this research had made a new formula as an attempt to update IHCM on unsignalized intersections. The overall calculation results gave the calculated value equal to the field value. This result was more likely to provide data on the performance of unsigned intersections accurately so that traffic problems could be resolved using appropriate analysis.

5. Discussion

This research aimed to update the performance of unsignalized intersections based on IHCM. The final results of the updating process are shown in Table 3.

Table 3. Updating the performance of unsignalized intersections.

No	Parameter	Symbol	Result
1	Passenger Car Equivalent	PCE	updated
2	Basic capacity	C_0	IHCM
3	The approach width	F_W	updated
4	Median	F_M	IHCM
5	City size	F_{CS}	not used
6	Environmental type, side friction and non-motorized vehicles	F_{RSU}	IHCM
7	Left turn	F_{LT}	updated
8	Right Turn	F_{RT}	updated
9	Minor road flow ratio	F_{MI}	updated
10	Delay	D	IHCM

Table 3 shows that there are several parameters considered for updating, namely the PCE values for all types of vehicles. The changes in the PCE values occurred in non-motorized ones which according to IHCM had no value. The results of updating show the PCE value of 0.45 for non-motorized ones. This is consistent with the study conducted by Rahman and Nakamura(2005) in calculating PCE based on average speeds. Updating the PCE value of motorcycles was proposed at 0.17, for which it was important to revise the PCE value as a result of a significant increase in the number of motorcycles (Tan, Tu, & Sano, 2018). Meanwhile, the PCE value for heavy vehicles was proposed at 2.2, where the PCE revision was based on the number of heavy vehicles that had increased at unsignalized intersections. The same thing was conducted by Saha et al. (2009) who calculated the PCE value for heavy vehicles based on the headway value as a result of the influence of the number and dimensions of heavy vehicles on intersection performance.

Another parameter that had been updated was the width of the approach. The results showed that there was a significant change in the size of approach width of each intersection, so it was necessary to update the formula of the adjustment factor for approach width. Chandra and Kumar (2003) stated that the approach width is important in determining the capacity because it affects the speed of the vehicles so that the updating of the adjustment factor for approach width can affect the intersection capacity. Moreover, the adjustment factor for left and right turns had also been updated because the movement of turning left and right at an unsignalized intersection had a significant change from the statement in IHCM which states that the ratio of vehicles turning left and right is only 10%. The reality in the field was very different, the turn ratio for each intersection was different, which was affected by the location of the intersection towards the center of urban activity. It was important to update the adjustment factor for left and right turns because it could affect the crossing capacity. As a matter of fact thatWu (1999); Brilon and Wu (2002) specifically calculated the movement of turning left, right and straight ahead which had a significant effect on the performance of unsignalized intersections. The adjustment factor for minor road flow ratio was the last parameter to be updated as a result of the increase in the number of vehicles from minor roads. IHCM states that the minor road flow ratio was only 20%, the reality in the field was different, which could be approximately > 40%.

There are three parameters of intersection performance that are not significant so it is suggested to keep using the equations in IHCM. The first is basic capacity although Puan et al. (2014) and Mehar et al. (2014) stated that it is necessary to revise the basic capacity. However, the calculation results show that the value of 2700 for the type-322 unsignalized intersection corresponded with the field data. Likewise, for the second parameter, the adjustment factor for median still used the equation in IHCM. Although several studies have stated that the median factor can affect road capacity (Liu, Lu, & Cao, 2009; Liu, Lu, Hu, & Sokolow, 2008), the results of field data showed that unsignalized intersections in Indonesia did not have a median on average on both minor and major roads. The third parameter was delay. The fixed delay equation was based on IHCM because the equation has included a complete calculation, namely delays on minor roads, delays on major roads, and geometric delays.

The adjustment factor for city size was the only parameter that was not used in updating the IHCM because it was found that there was no difference between the number of vehicles, driver behavior, and conflicts that occur at unsignalized intersections in small, medium, and large-sized cities. Therefore, the performance of the intersection capacity was determined by not using the adjustment factor for city size.

6. Conclusion

This research was conducted to obtain updates on the performance of unsignalized intersections based on theIHCM. The research locations were selected in 12 cities in Indonesia which consisted of 20 unsigned intersections. The important points found in this research are as follows:

(1) Updating was conducted on the parameters of the unsignalized intersections in IHCM. The first stage was updating the PCE values resulting in values of 0.45 for non-motorized vehicles, 0.17 for motorcycles, 1 for light vehicles, and 2.2 for heavy vehicles.
(2) The second stage was updating the parameters of unsignalized intersection capacity. The results obtained at this stage were a new formula for adjustment factor for approach width, adjustment factor for right turn, adjustment factor for left turn, and adjustment factor for minor road flow ratio. Parameters that still used the formula in IHCM were basic capacity, median factor and environmental type factor, side friction, and non-motorized vehicles. The city size factor was not used to update the performance of unsignalized intersections.
(3) Based on the new formula found in the updating process of unsignalized intersections, the value of calculated delay was obtained. To validate the results of the updating, a difference test was conducted between the calculated delay and the field delay. The results indicated that there was no difference between the two so that it could be said that the updating process had corresponded with the field data.

The results of this study obtained a new formula for updating IHCM which is expected to be used to analyze the performance of unsignalized intersections in present and future traffic.

Regarding the objective of this research, it only examined the performance parameters of intersections at IHCM, so that it is expected further research can include factors that affect the turning movement of vehicles, for example road conditions and environment, driver behavior, and vehicle conflicts. By including these factors, it is hoped that it can provide an overview of the actual unsignalized intersections. In addition, in order to improve the performance of unsignalized intersections, it is suggested to impose limits on the number of vehicles that pass, especially on motorcycles. In addition, to assess the performance of intersections to be more accurate, the limitation can be a solution to reduce private vehicles in the society.

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