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Adjusted saturation flow of some signalized intersection in Semarang, Indonesia

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Abstract. Indonesian Highway Capacity Manual or IHCM (1997) is a manual used to analyse performance of Indonesia's road network. It has been more than 20 years since the manual is firstly published, so that some parameters such as passenger car equivalent (pce) and base saturation flow (S_0) are no longer in accordance with actual conditions, which is indicated by significant differences between IHCM analysis results and empirical data. Several studies have been conducted in many cities and rural areas across Indonesia to explore pce, base saturation flow or other adjustment factors, in order to update IHCM, so in general, this manual will be more appropriate for current traffic conditions. This study is aimed at obtaining adjusted saturation flow from three signalized intersections in Semarang City, based on a comparison between predicted queue lengths and the empirical ones. Using the vehicle departure time slice data for green time, the pce and saturation flow was adjusted using regression method. Adjusted saturation flow at the observed intersection can be simplified in equation $S = 506.48 W_e + 1857.9$. Addition of variables still needs to be considered to gain a more general equation.

1. Introduction

Indonesian Highway Capacity Manual (IHCM) or Manual Kapasitas Jalan Indonesia (MKJI) is a manual published in 1997 that is used to analyse performance of Indonesia's road network. It has been more than 20 years since the manual is firstly published, so that some parameters are no longer in accordance with actual conditions, which is indicated by significant differences between IHCM analysis results and empirical data. Several studies have been conducted in many cities and rural areas across Indonesia to explore adjustment factors or parameters, in order to update IHCM, so that, in general, this manual will be more appropriate for current traffic conditions.

An update for this manual had been established in 2014, namely Pedoman Kapasitas Jalan Indonesia (PKJI) or the Indonesian Highway Capacity Guidance (IHCG). Overall, for the signalized intersection chapter, the concept has no significant difference to IHCM, except for motorcycle passenger car equivalent (pce) value on a protected intersection, which is equal to 0.2 for IHCM, while for IHCG it is equal to 0.15. One implementation of this manual update or this guidance was conducted by Indriastuti and Priyono [1] on Gajah Junction, Semarang, Indonesia, by comparing the queue length produced by the guidance (analytical process) and the empirical data. It resulted that the difference between analytical and empirical data of the number of passenger car unit that remained from previous green phase (NQ1) and the number of passenger car unit that arrived during red phase (NQ2) were still acceptable, but the queue length occurred were significantly different.



The results produced by Indriastuti and Priyono [1] provide evidence that in-depth research is still needed to find other alternative to improve the IHCM. Several studies have been conducted in many cities and rural areas across Indonesia to explore pce, saturation flow or other adjustment factors, in order to update IHCM.

Kariadi, Kaligarang and Simongan Intersection in Semarang City are located adjacent. All of them lay on a secondary arterial. Still, each intersection may have unique geometric and traffic characteristics, and a generalization based on similar features might be needed. Since IHCM can no longer be used to analyse the performance of these intersection, a modification might be needed to explore the most suitable performance prediction, such as saturation flow. This study is aimed at obtaining adjusted saturation flow (S) and generating the model of saturation flow that is more suitable for the observed signalized intersections characteristics than using the IHCM parameter value.

2. Saturation flow

2.1. Definition of saturation flow

Saturation flow is the rate of queue discharge in an approach during green signal in a given condition [2]. Saturation flow is assumed to be constant during the duration of green. According to IHCM [2], in practice, the discharge rate starts from 0 at the beginning of green and reaches its peak value after 10 – 15 seconds. It drops slightly until the end of green, then continues during amber and all-red when it drops to 0. It normally takes about 5 – 10 seconds after the beginning of red signal. The basic model for saturation flow is illustrated in figure 1.

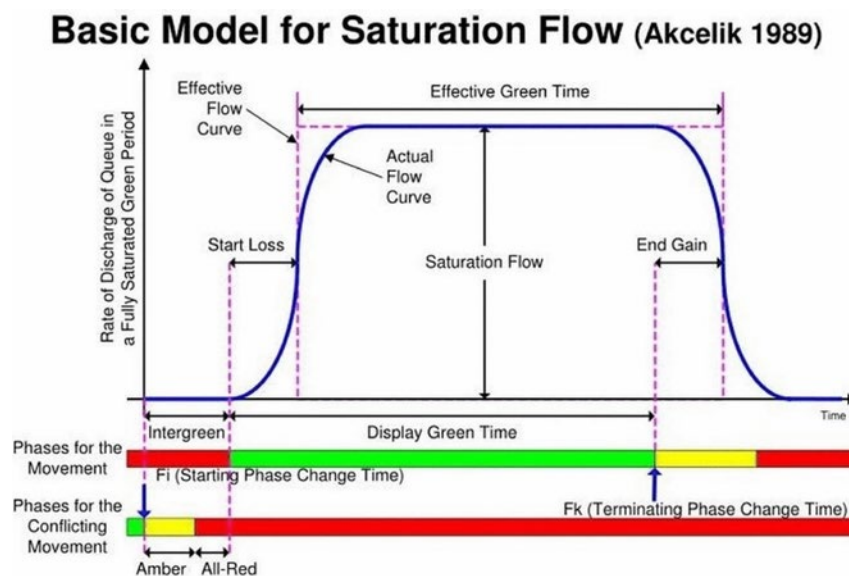


Figure 1. Basic model for saturation flow (Akcelik) [2].

2.2. Saturation flow models

Saturation flow models have been developed in many countries, adjusted to the traffic conditions in the region. Saturation flow is the product of multiplication between base saturation flow and some adjustment factors. In some studies, base saturation flow is influenced by the effective width of the approach, as shown in table 1.

Table 1. Base saturation flow models for protected approach.

Model	Region/country	Reference
$S_0 = 600 W_e$	Indonesia	IHCM [2] & IHCG [3]

Model	Region/country	Reference
$3 \text{ m} < W_e < 8 \text{ m} : S_0 = 600 W_e$	Bandung City/ Indonesia	Susilo and Solihin [4]
$9 \text{ m} < W_e < 12 \text{ m} : S_0 = 500 W_e + 400$ $S_0 = 1159.407 - 83.523 W_e$ $+ 246.149 W_{\text{shoulder}} - 9.938 W_{\text{exit}}$	Malang City/ Indonesia	Bowoputro et al. [5]
$g \leq 16 \text{ sec} : S_{0w} = 35 W^3 - 509 W^2 + 4590 W$ $g > 16 \text{ sec} : S_{0w} = 42 W^3 - 642 W^2 + 4976 W$	Ho Chi Min City/ Vietnam	Nguyen [6]

3. Research methodology

The idea of this research is to adjust the value of analytical base saturation flow to the empirical base saturation flow. The adjusted value was used to provide analytical intersection performance that suitable with the real conditions. In this case, the intersection performance measured is the queue length. To obtain this adjusted saturation flow, it is necessary to first adjust the passenger car equivalence (pce). After determining the adjusted pce and saturation flow, the performance of signalized intersection was analysed by modifying the IHCM analysis. The result, adjusted queue length, will be compared to empirical queue length.

Three signalized intersections observed were Kariadi, Kaligarang and Simongan intersections in Semarang City, Indonesia. Empirical saturation flow was taken in 5-seconds-time-slices in each period of green time during peak hour. A measurement of queue length and observation of the cycle time and phase were also carried out. From pilot survey, peak times on those locations are usually happened on weekdays, at about 06.30 – 07.30 and 16.00 – 17.00. Thus, the observations were conducted based on these findings. Geometric data such as approach width, effective width, etc was measured manually.

Pre-adjusted saturation flow was analysed using the ratio of saturation flow per time slice to maximum saturation flow in green time period. This value was used to form a multi-linear regression equation to analyse the adjusted pce value. Using this adjusted pce, the adjusted saturation flow can be calculated. Next, the queue length was analysed using IHCM formula : $Q_L = NQ_{\max} \times \frac{20}{\text{approach width}}$. NQ_{\max} is the the total value of the number of vehicles remaining from the previous green period and the number of vehicles approaching the intersection during the red period.

To validate the adjusted pce values and saturation flow, a two-tailed t-test was carried out to see the similarity of the analytical queue length with the empirical queue length.

4. Data

4.1. Intersection Geometric

Geometric data of the observed intersections is shown in table 2.

Table 2. Geometric data.

Inter-section	Approach	Side Friction Class	Divided	Left Turn on Red (LTOR)	Approach Width (m)	Direction ^a	Effective width occupied by each direction (m)
Kariadi	North	Medium	No	No	8.5	ST1	4.5
						ST2	4.5
						RT	4.0
	South	Low	Yes	Yes	8	ST	5.0
						RT	3.5
Kaligarang	South	Low	No	No	7	ST	2.6
						RT	2.9
						LT1	2.5
						LT2	2.5

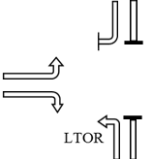
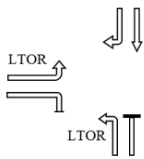
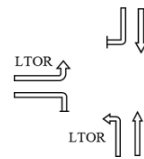
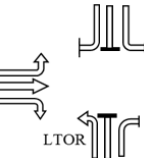
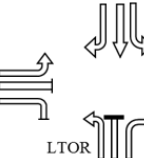
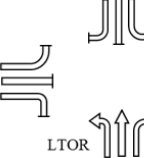
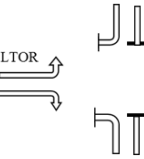
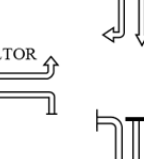
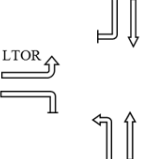
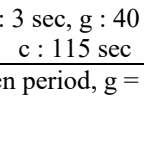
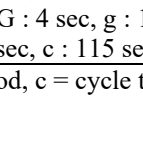
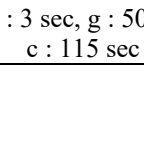
Inter-section	Approach	Side Friction Class	Divided	Left Turn on Red (LTOR)	Approach Width (m)	Direction ^a	Effective width occupied by each direction (m)
Kaligarang	East	Medium	Yes	Yes	9	ST	5.1
						RT	1.9
	West	Low	Yes	No	7	ST	3.6
						RT	2.0
Simongan	South	Low	Yes	Yes	8.5	LT	1.4
						RT	6.0
	East	Low	Yes	No	7	ST	3.5
						LT	3.5
	West	Low	Yes	No	7	RT	3.5
						ST1	3.5
						ST2	3.5

^a ST = Straight Trough, LT = Left Turn, RT = Right Turn

4.2. Cycle time

On Kariadi and Kaligarang Intersections, there is no difference between the cycle time and phase setting of morning and afternoon. Whilst, on Simongan Intersection, the phase setting of morning and afternoon are similar, but the cycle time setting differ. The data are shown in table 3.

Table 3. Cycle time and phase setting.

Intersection	Phase-1	Phase-2	Phase-3
Kariadi (morning and afternoon)	 IG : 3 sec, g : 35 sec, c : 115 sec	 IG : 4 sec, g : 25 sec, c : 115 sec	 IG : 3 sec, g : 45 sec, c : 115 sec
Kaligarang (morning and afternoon)	 IG : 3 sec, g : 25 sec, c : 164 sec	 IG : 3 sec, g : 70 sec, c : 164 sec	 IG : 3 sec, g : 60 sec, c : 164 sec
Simongan (morning)	 IG : 3 sec, g : 35 sec, c : 100 sec	 IG : 4 sec, g : 15 sec, c : 100 sec	 IG : 3 sec, g : 40 sec, c : 100 sec
Simongan (afternoon)	 IG : 3 sec, g : 40 sec, c : 115 sec	 IG : 4 sec, g : 15 sec, c : 115 sec	 IG : 3 sec, g : 50 sec, c : 115 sec

Note: IG = intergreen period, g = green period, c = cycle time

4.3. Empirical saturation flow

Empirical saturation flow was obtained from the observations of the discharged vehicles in 5-seconds time-slices in each green time period at morning and afternoon peak hours. The example of saturation flow data at one of intersection evaluated, i.e, Kariadi intersection, is shown in figure 2.

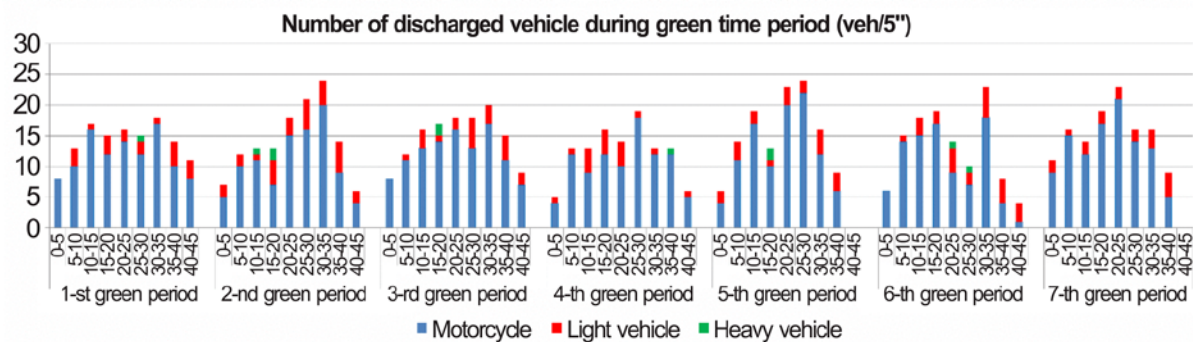


Figure 2. Five-seconds time-slice saturation flow at morning peak on Kariadi intersection (South approach – Straight movement).

4.4. Queue length

Queue length data is measured on site, as shown in table 4.

Table 4. Empirical queue length.

Intersection	Approach	Direction	Queue Length (m)	
			Morning	Afternoon
Kariadi	North	ST1	119	94
		ST2	0	0
		RT	87	82
	South	ST	98	125
	West	RT	112	118
Kaligarang	South	ST	111	102
		RT	111	102
		LT1	111	102
	East	LT2	0	0
		ST	121	119
		RT	137	130
Simongan	South	ST	82	58
		RT	115	121
		LT1	61	61
	East	ST1	102	91
		ST2	0	0

5. Discussion

5.1. Adjusted passenger car equivalent (pce)

Adjusted pce is needed to convert empirical data of saturation flow – from vehicle/5" to pcu/hg, and traffic flow – from vehicle/hour to pcu/h, in order to obtain the analysed queue length.

Adjusted pce of the sample intersection (Kariadi Intersection for South approach – straight movement) was analysed as follows :

- a. Calculate IHCM base saturation flow (S_{0-IHCM})
Effective width for the straight movement at Kariadi Intersection (South approach) is 5 m (from table 2), so that IHCM base saturation flow was:
 $S_{0-IHCM} = 600 \times W_e = 3000 \text{ pcu/hg}$
- b. Calculate saturation flow per time slice (S_{-TSi})
From figure 2, in the first green time period, at the fifth segment (25'' – 30''), the number of discharge vehicles were 12 MCs, 2 LVs, and 1 HV. Converted to vehicle/15 minutes by a multiplication with 180, thus the value of saturation flow was:
 $S_{-TS1} = S_{-TS1 LV} \times 180 + S_{-TS1 HV} \times 180 + S_{-TS1 MC} \times 180 = 2700 \text{ vehicle/15'}$.
Thus, S_{-TSi} value was calculated for all time slices and all green time periods.
- c. Check the maximum saturation flow (S_{-TSmax})
The maximum saturation flow was 3060 vehicle/15' that occurred at the sixth time slice of the fifth green time period (calculated from data in figure 2).
- d. Calculate the pre-adjusted base saturation flow ($S_{0-preadjusted}$)
The pre-adjusted base saturation flow ($S_{0-preadjusted}$) was obtained by multiplying the value of IHCM base saturation flow (S_{0-IHCM}) with the saturation flow ratio (RS).
$$RS = \frac{S_{-TSi}}{S_{-TSmax}}$$

 $S_{0-preadjusted} = S_{0-IHCM} \times RS = 2647.05 \text{ pcu/hg}$
- e. Form multi-linear regression equation
The multi-linear regression equation was formed in order to generate an adjusted pce which was more suitable for specific condition. This equation used the pre-adjusted base saturation flow ($S_{0-preadjusted}$) as dependent variable, and saturation flow per time slice (S_{-TSi}) as independent variable. Since the value of ($S_{0-preadjusted}$) was in pcu/hg, S_{-TS1} also has to be converted from vehicle/5'' as follows :
$$S_{0-preadjusted} = S_{-TS1 LV} \times 720 \times pce_{LV} + S_{-TS1 HV} \times 720 \times pce_{HV} + S_{-TS1 MC} \times 720 \times pce_{MC}$$

Continuing the example, thus the equation for the first green time period is:
$$1207,05 = 1 \times 720 \times pce_{LV} + 12 \times 720 \times pce_{MC}$$

The procedur was repeated for the rest of *time slice* so that there was a set data. This set data was processed using multilinear regression, to gain a sat data of pce, as shown ini table 5.

Table 5. Adjusted passenger car equivalent (pce).

Intersection	Approach	Direction	Adjusted pce			
			Morning		Afternoon	
			MC	HV	MC	HV
Kariadi	North	ST1	0.316	0.657	0.304	0.659
		ST2	0.356	0.882	—	—
		RT	0.544	0.949	0.417	1.000
	South	ST	0.319	1.122	0.333	0.924
		RT	0.356	0.724	0.367	1.000
		ST	0.286	1.519	0.630	1.074
Kaligarang	South	RT	0.267	0.513	0.784	1.433
		LT1	0.576	1.118	0.657	0.829
		LT2	0.604	1.375	0.656	1.000
	East	ST	0.467	0.774	0.243	0.913
		RT	0.819	1.000	0.729	1.000
		ST	0.403	1.036	0.501	1.155
	West	RT	0.594	1.000	0.500	0.833
		LT	0.667	1.167	0.458	1.000

Intersection	Approach	Direction	Adjusted pce			
			Morning		Afternoon	
			MC	HV	MC	HV
Simongan	South	RT	0.445	0.783	0.352	1.170
		ST	0.485	0.889	0.383	0.765
	East	LT	0.423	0.923	0.284	0.676
		RT	0.267	0.756	0.410	0.901
	West	ST1	0.400	0.848	0.278	0.856
		ST2	0.338	0.796	0.459	0.792

From table 5, some findings are obtained, as follows:

1. The adjusted pce analysis was carried out in each direction of all approaches since every direction has different traffic characteristics. Further research is still needed to generate this value.
2. The pce value of MC at these intersections tend to be greater than IHCM [2] and IHCG [3]. Whilst, pce value of HV tend to be smaller.
3. On Kaligarang Intersection (East), pce value of MC for right turning movement was considered too large. This could happened because the right turning lane was used by straight movement, so that some right turning movement were blocked by the queue of straight-moving vehicles.
4. The existence of LTOR lane affected on the value of pce. Approaches with LTOR lane generated lower value of HV pce than ones with no LTOR lane, since left-turning heavy vehicles can quickly discharged with less obstruction to other movements.

5.2. Adjusted saturation flow (pcu/hg)

Using adjusted pce for each approach, adjusted saturation flow can be calculated, as shown in table 6.

Table 6. Adjusted saturation flow.

Intersection	Approach	Direction	Effective width	Adjusted Saturation Flow			
				Morning		Afternoon	
			(m)	(pcu/5'')	(pcu/hg)	(pcu/5'')	(pcu/hg)
Kariadi	North	ST1	8.5	7.13	5130	7.30	5259
		ST2	5.0	4.56	3281	2.68	1933
		RT	5.0	8.94	6434	8.60	6189
	South	ST	5.0	7.03	5063	6.96	5010
		West	RT	4.0	8.14	5857	8.69
	East	ST	7.0	6.18	4453	4.90	3531
RT		7.0	2.95	2124	2.55	1834	
Kaligarang	West	ST	7.0	5.85	4211	6.02	4335
		RT	7.0	3.76	2710	3.39	2443
		LT	7.0	2.48	1785	2.11	1520
	South	ST	8.0	4.96	3569	8.76	6305
		RT	8.0	5.88	4234	11.18	8051
		LT1	7.0	4.56	3283	7.10	5112
		LT2	3.0	3.84	2763	3.55	2554

Intersection	Approach	Direction	Effective width (m)	Adjusted Saturation Flow			
				Morning		Afternoon	
				(pcu/5")	(pcu/hg)	(pcu/5")	(pcu/hg)
Simongan	East	ST	7.0	5.05	3635	4.65	3350
		LT	7.0	3.80	2737	3.27	2414
	South	RT	6.0	7.34	5287	5.21	3752
		RT	7.0	5.50	3957	6.39	4598
	West	ST1	7.0	3.80	2734	4.76	3430
		ST2	4.0	4.90	3531	3.47	2501

The relationship between effective width occupied for each movement and adjusted saturation flow can be seen in figure 3. The greater the effective width of the road, the higher the value of adjusted saturation flow. Using this equation, the value of adjusted saturation flow might be higher than basic saturation flow using IHCM equation ($S_0 = 600 \times \text{effective width}$). This might be more relevant, due to the increase of traffic volume trend in Semarang city, especially on the observed intersections.

Still, the relationship between these two variables was not very good, as indicated by the R^2 value is quite low. Possibly, there were other variables that need to be considered, such as the proportion of the direction of movement or the proportion of vehicles or the road user obedience.

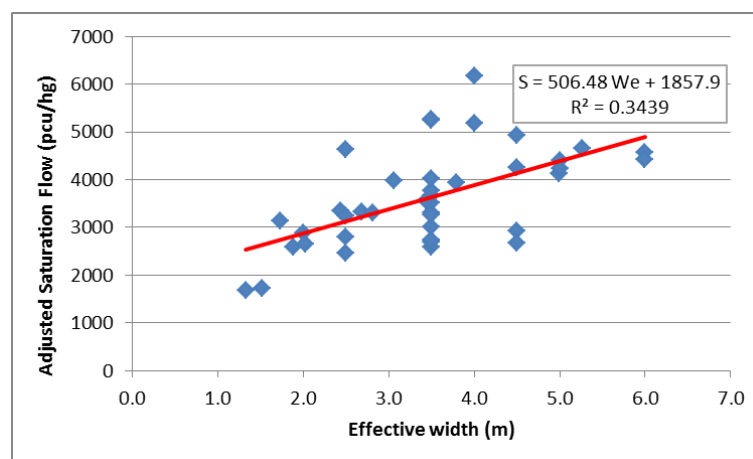


Figure 3. Relationship between effective width and adjusted saturation flow (morning and afternoon peak time).

5.3. Queue length

Queue length was calculated using three methods, namely IHCM, IHCG and adjusted pce and saturation flow. The results are depicted in table 7.

Table 7. Analytical queue length.

Inter-section	Approach	Direction	Queue Length (m)					
			IHCM		IHCG		Adjusted pce and S_0	
			Mor.	Aft.	Mor.	Aft.	Mor.	Aft.
Kariadi	North	ST1	176	47	53	40	93	96
		ST2	103	64	36	48	98	111
		RT	124	54	46	47	113	122
	South	ST	118	136	43	108	84	143
	West	RT	168	155	55	120	128	141

Inter-section	Approach	Direction	Queue Length (m)					
			IHCM		IHCG		Adjusted pce and S_0	
			Mor.	Aft.	Mor.	Aft.	Mor.	Aft.
Kaligarang	South	ST	29	38	29	23	48	73
		RT	121	80	99	20	105	135
		LT1	33	53	30	23	76	90
		LT2	63	64	47	33	104	103
	East		87	116	73	35	122	135
	West		96	113	80	40	156	173
	South		71	48	58	40	127	76
Simongan	East		58	67	50	54	91	102
	West	RT	39	37	29	27	57	42
		ST1	46	35	34	30	51	57
		ST2	131	100	69	84	160	70

The queue length will be compared to empirical queue length, to determine the closest methods that can predict the most suitable condition to the real traffic.

5.4. Validation

Validation was carried out by comparing intersection performance, in this case the queue length, between the field conditions and the results of the analysis, using the saturation flow and pce from IHCM and IHCG, and from the results of this study. Using a two-tailed t-test, the following results were obtained:

Table 8. Results of two-tailed t test.

Intersection	Empirical vs analytical queue length ^a					
	IHCM		IHCG		Adjusted pce and S_0	
	t_{stat}	t_{table}	t_{stat}	t_{table}	t_{stat}	t_{table}
Kariadi	2.45	2.31	-1.87	2.31	2.12	2.31
Kaligarang	-2.32	2.22	-4.04	2.22	1.25	2.22
Simongan	2.45	2.31	-0.13	2.31	0.64	2.31

^a the shaded values indicate the rejection results

Table 8 shows that among the three methods, IHCM was the worst approach, since the $t_{stat} > t_{table}$ (IHCM queue length was significantly differ from the empirical ones) and the proposed adjusted pce and S_0 produced the best results among all method evaluated.

6. Conclusions

From the results of the analysis, the following conclusions can be drawn:

1. The adjusted pce analysis was carried out in each direction of all approaches since every direction has different traffic characteristics. Further research is still needed to generate this value.
2. The pce value of MC at these intersections tend to be greater than IHCM and IHCG. Whilst, pce value of heavy vehicle tends to be smaller.
3. Adjusted saturation flow at the observed intersection can be simplified in equation $S = 506.48 W_e + 1857.9$. Additional variables are still needed to be considered to generate more general equation.

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