Influence Of Opposed Right-Turns On Saturation Flow At Signalised Intersections

Jany Agustin

The objective of the project was to study the influence of opposed right-turns on saturation flow. It was intended to use this as a tool for design and timing of signalised intersections because no guidance procedure was available in Indonesia.

Data was collected from two signalised intersections in Bandung by video-camera. Three theoretical models were discussed and applied to the collected data and then compared with the observations. The theoretical methods increasingly overestimated the saturation flow at higher approach width.

Generally good correlations were obtained between observed saturation flow, approach width and opposing flow. However, this was not the case regarding the ratio of right-turns.

Field observations showed that the right-turning vehicles did not give way to opposing flow, which is an important difference between Indonesian and Western traffic behaviour. Therefore, it is necessary to develop a model for capacity calculations applicable to Indonesian conditions based on further data collection for a wide range of conditions and sites.

INTRODUCTION

Background

At signalised intersections, right-turning vehicles have to share green time with opposing flow, unless this conflict is time-separated by means of special phases for right-turning traffic. When the opposing traffic flow is high, right-turning vehicles may be considerably delayed and may also block other traffic streams. Therefore, the capacity of two-phase, four-way intersections is very much affected by right-turning vehicles.

Theoretical models based on experimental data have been developed in Australia, Sweden and USA (1, 2 and 3) for calculation of signal timing, capacity and delay in these cases. The results probably cannot be directly applied in Indonesia. The main difference is in the way in which traffic behaves, and also the traffic composition is very much different from Western conditions.

It is obvious that research on the signalised intersection system of Bandung to develop a similar method adjusted to Indonesian traffic conditions would be desirable. This could hopefully be used as a tool for design and timing of signalised intersections in Bandung and elsewhere.

Objectives

Three objectives formed the basis of this study:

1. To measure the influence of opposed right-turns on saturation flow at intersections controlled by two-phase traffic signals.
2. To apply theoretical models developed in Australia, Sweden and USA to the collected data.
3. To analyse and evaluate the results of field observations and of theoretical models.

The different vehicle types were considered, motorcycles, cars and heavy vehicles. None of the theoretical models developed in Australia, Sweden and USA account for motorcycles in the calculations. Level of service was not considered in this study.

LITERATURE REVIEW

Computations of saturation flow begin with the selection of an ideal/base value of saturation flow rate which is then adjusted for a variety of prevailing conditions that are not ideal. The right-turn adjustment factor is based on a number of variables including opposing flow, proportion of right-turning vehicles, and number of pedestrians using the conflicting crosswalk.

Three theoretical methods from Australia, Sweden and USA, are based on similar assumptions regarding opposed turn departure characteristics, as illustrated in Fig. 1.

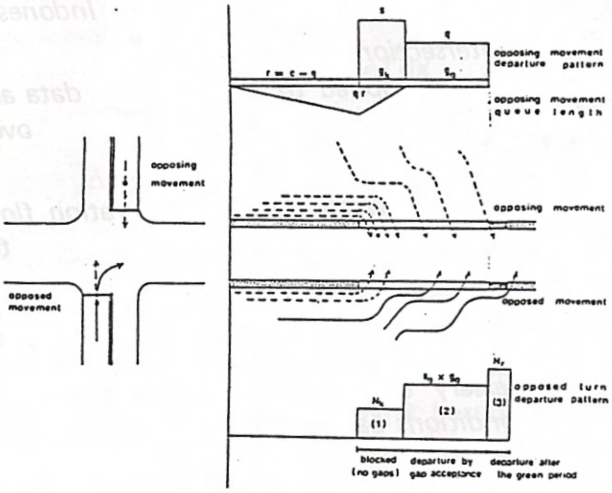


Fig. 1 — Opposed Turn Departure Characteristics

Australian Method (1).

The following method is recommended for estimation of opposed turn saturation flow:

$$s = (f_w . f_g / f_c)\, s_b$$

where:

s = saturations flow estimate in veh/h;

s_b = base saturation flow in through car units/h for estimation by environment class and lane type;

f_w = lane width factor;

f_g = gradient factor;

f_c = traffic composition factor for a particular vehicle type and turning traffic mix is.

Swedish Method (2)

The determination of a base value takes into account the proportion of turning vehicles and the degree of conflict with other vehicles and pedestrians.

$$s = f_c \cdot f_g \cdot f_w \cdot s_b$$

Where:

s_b = base saturation flow value;

f_c = traffic compostion factor;

f_g = gradient factor;

f_w = lane width factor.

USA Method (3)

Computation of saturation flow is carried out as follows:

$$s = s_o . N . f_w . f_{Hv} . f_g . f_p . f_{bb} . f_a . f_{RT} . f_{LT}$$

For variables other than f_{RT}, plase refer to HCM 1985, USA.

f_{RT} = adjustment factor for right-turns in the lane group.

The right-turn adjustment factor reflects three component flows during any given green phase:

(1) through and left-turning flows in a shared lane at the start of the green until a right-turning vehicle arrives, blocking the lane while waiting to turn.

(2) shared lane or right-turn lane flows during the unsaturated period of opposing flow; and

(3) right turns made at the end of the green phase by vehicles already waiting in the intersection for an appropriate gap in opposing flow.

All the methods assume that priority is given to the opposing flow until a queue in the opposing flow disappears. The acceptable gaps occurring in the opposing flow are used for right-turns to discharge. The Australian method does not take into account the first component of flow, through or left-turning vehicles that can be discharged from the lane until the lane gets blocked by queueing right-turns.

DATA COLLECTION

Site Selection and Equipment Used

The choice of study locations was based on the following requirements:

(1) The intersection approach studied should have one lane with right turning permitted, opposed by oncoming traffic in the same phase.

(2) There should ideally be little or no interference to the flow of traffic by unmotorized vehicles.

(3) A high observation point should be available close to the intersection to be able to use the video-camera.

(4) Good conditions of geometric design and pavement are required, particularly having uniform road width and lack of pavement deformation.

(5) The sites should have reasonably level profiles with straight approaches and departures.

Considering the above requirements, the following sites were chosen.

a. Intersection of Jalan Pasirkaliki and Jalan Pasteur (see Figure 2A) in Bandung.
b. Intersection of Jalan Lombok and Jalan Aceh (see Figure 2B) in Bandung.

The equipment used is listed below.

a. Video-camera SONY BMX 500 p: for measurements of flow, saturation flow, and for driver behaviour observation.
b. EPSON HX 20: for measurement of saturation flow.

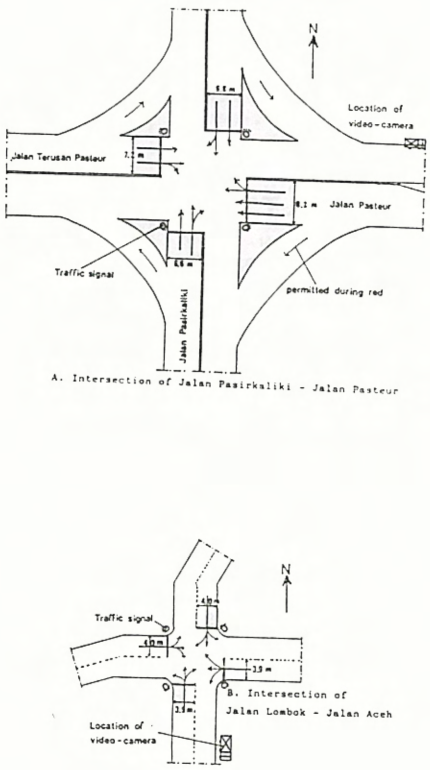
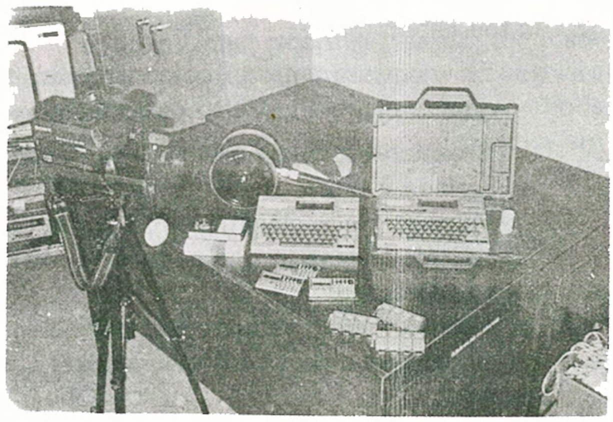


Fig.2 — Sites Studied

c. Hand-tallies: for flow measurement.
d. Stop-watches: for delay measurement.
e. 14-m skylift: to provide a high observation point to obtain the best coverage by video-filming of the intersection approach studied.

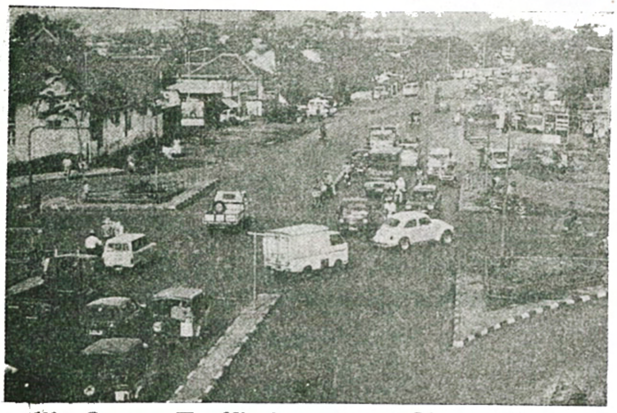
The actual time of commencement of each green phase on the approach under study was indicated by sound to the video-camera.



Ills. 1 — Equipment used in the collection of data

Methods of Collecting Data

1. In the field
   a. Traffic movement observation using video camera.
      Using a sky-lift, the video-camera was placed high enough to cover the intersection area and enable recording of the movements of vehicles to measure saturation flow at different levels of opposing flow, and to observe driver behaviour especially the right-turning behaviour.
   b. Saturation flow measurement using EPSON HX 20
      A program for determining saturation flow was loaded into the portable computer EPSON HX 20.
      Input data was time slice (ie 4 seconds), number of vehicle classes (ie 3) and p.c.u for each class.



Ills. 2 – Traffic Movement Observation

2. In the Laboratory
   a. Flow measurement, compositional and directional, Using Video-Camera.

      Green times were sliced into 4-second periods.
      Vehicles were classified into three types and movement in one of three directions was recorded.
      The number of vehicles for each category in each time slice of 4 seconds was counted.

   b. Saturation flow measurement, using video-camera.
      As indicated in (a) but the counting of vehicles was done only for saturated conditions.

   c. Driver behaviour observation using video-camera.
      Observation was carried out particularly for right-turning behaviour. The behaviour was evaluated by observing the movement of the vehicles during the first, the second, ..., the n^{th} 4-second time periods in a cycle.

   Video-camera recordings were made during morning peak hours in February and March 1986. A tape recording speed of 18.73 mm/sec was used.
   Recording was done only on clear days and under dry pavement conditions. At least 600 signal cycles per intersection were recorded.

Problems Encountered and Possible Sources of Errors.

a. The EPSON HX 20 instrument caused problems during data recording due to the insufficient sensitivity of the push-buttons. Data was not always recorded when the buttons were pressed. Occasionally when a button was strongly pressed a repetition of date points was recorded instead of one. Because of this, the results of the EPSON HX 20 field recordings were excluded from the subsequent analysis.
b. It was difficult to obtain consecutive periods with saturated conditions, i.e. during several cycles, due to the constraints of time and funding.
c. Although all traffic signals in Bandung are of the fixed-time type, the signal timing fluctuates mainly due to varying voltage. This was particularly true for the intergreen time which could vary between 4 and 6 seconds at one intersection. This caused confusion among the road users and did not encourage observance of the regulations.
d. The field observations showed that lane use at the same approach was not constant. The traffic sometimes formed into four lanes on the Pasteur approach instead of three lanes, possibly due to lack of lane markings.

RESULTS AND ANALYSIS

Relationship Between Saturation Flow, Proportion of Right-turns and opposing flow.

Observed saturation flows were plotted as a function of the proportion of right-turns for a given range of opposing flows.

Regression analysis was made with data grouped according to varying opposing flow ranges (100–200, 200–300, ..., 900–1000 pcu/h).
Correlation coefficient (r) were also calculated. The following variabels were examined in the regression analysis:

1. Proportion of right-turns, PORT
2. Saturation flow, SATFL

The results are summarised in Table 1 some data for given ranges of opposing flows showed good correlations, i.e. in the approach Pasteur for opposing flow 600–700 pcu/h and apporoaches of intersection Jl. Lombok – Jl. Aceh for

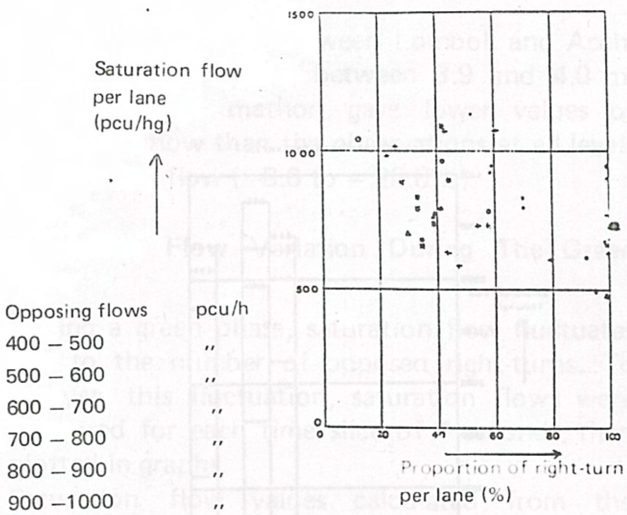


Fig. 3 — Relationship between saturation flow and proportion of right-turns for median lanes of approaches in the intersection Jalan Pasirkaliki — Jalan Pasteur.

Table 1 — Regression analysis with data grouped according to varying opposing flow

Approach	Range of Opp. flow, pcu/h	Regression equations	r
Sukajadi + Pasirkaliki Pasteur	700 – 800	Y = 1972 + 1880 PORT *)	0.38
	800 – 900	Y = 2491 – 1067 PORT *)	0.10
	600 – 700	Y = 4007 – 2103 PORT	0.72
	700 – 800	Y = 1369 + 2639 PORT *)	0.94
Ter. Pasteur	500 – 600	Y = 1663 + 2557 PORT *)	0.88
Median lane	500 – 600	Y = 1127 – 232 PORT	0.13
	600 – 700	Y = 675 + 547 PORT *)	0.72
	700 – 800	Y = 858 + 153 PORT *)	0.24
	800 – 900	Y = 867 + 513 PORT *)	0.41
	900 – 1000	Y = 1019 – 235 PORT	0.46
Lombok + Aceh	200 – 300	Y = 1475 + 508 PORT *)	0.18
	300 – 400	Y = 1635 – 1015 PORT	0.61
	400 – 500	Y = 1805 – 906 PORT	0.49
	500 – 600	Y = 1458 + 99 PORT *)	0.24
	700 – 800	Y = 1389 – 503 PORT	0.94

*) not expect[illegible]

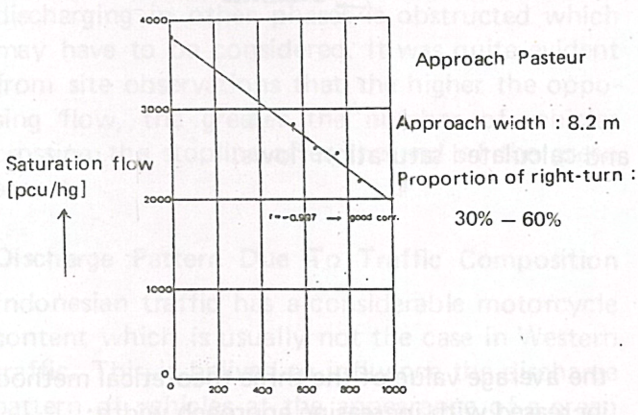


Fig. 4. — Relationship between saturation flow and opposing flow for approaches of intersection Jalan Pasirkaliki — Jalan Pasteur.

opposing flow 300–400 and 700–800 pcu/h. For a certain range of proportion of right-turns, regression analysis was also made excluding the variable proportion of right-turns.
See Fig 4. Good correclations were obtained for the apporoaches Terusan Pasteur, Pasteur, Lombok and Aceh. For the approaches Pasirkaliki and Sukajadi, the correlation was not significant, possibly because the range of opposing flows observed was small.

Saturation Flows Calculated from The Theoretical Methods.

With the conditions recorded during the data collection as an input, saturation flows were calculated using the three theoretical methods described in Literature Review. The results are presented in Table 2.

Table 2— Saturation flows, observed and calculated from the theoretical methods.

Opposed Condition

Approach	No. of lanes	Approach Width (m)	Prop. of right-turns (%)	Opposing flow (pcu/hr)	Saturation flow (pcu/hg) Aust.	Swed.	HCM'85	Obs.
Sukajadi	2	6.6	12.6	701	3046	2857	2830	1837
			18.4	832	2451	2466	2271	1848
			21.6	894	2196	2349	2232	1986
			15.3	827	2588	2428	2405	2068
			15.1	855	2332	2347	2212	2208
			19.0	783	2360	2409	2319	2243
			15.9	753	2570	2440	2419	2202
			21.3	803	2263	2303	2167	2246
			18.0	867	2183	2318	2183	2457
Pasir-kaliki	2	8.6	9.8	628	3381	3144	3183	2338
			21.2	738	2410	2826	2386	2545
			9.7	762	2833	2726	2805	2405
			12.9	326	2493	2569	2469	2637
			17.7	967	2692	2187	2132	2287
			14.3	966	2388	2403	2378	2248

Opposed Condition

Approach	No. of lanes	Approach Width (m)	Prop. of right-turns (%)	Opposing flow (pcu/hr)	Saturation flow (pcu/hg) Aust.	Swed.	HCM'85	Obs.
West Aceh	1	4.0	1.3	378	1638	2016	1884	1380
			4.8	683	1411	1495	1597	1178
			1.3	720	1529	1855	1766	1398
			3.1	846	1431	1753	1570	1342
			1.0	545	1576	1786	1827	1390
			6.0	525	1500	1727	1715	1552
			5.4	465	1555	1855	1776	1484
North Lombok	1	4.0	22.1	220	1517	1965	1783	956
			27.0	415	1194	1427	1287	1269
			34.1	610	731	756	661	1326
			32.9	935	706	686	553	1689
			65.4	741	444	435	371	1108
			48.0	787	590	459	420	1081
			44.1	480	893	1058	964	1464
			47.9	559	738	771	879	1582

Comparison between average observed and calculated saturation flows using the theoretical methods are shown in Figure 5.

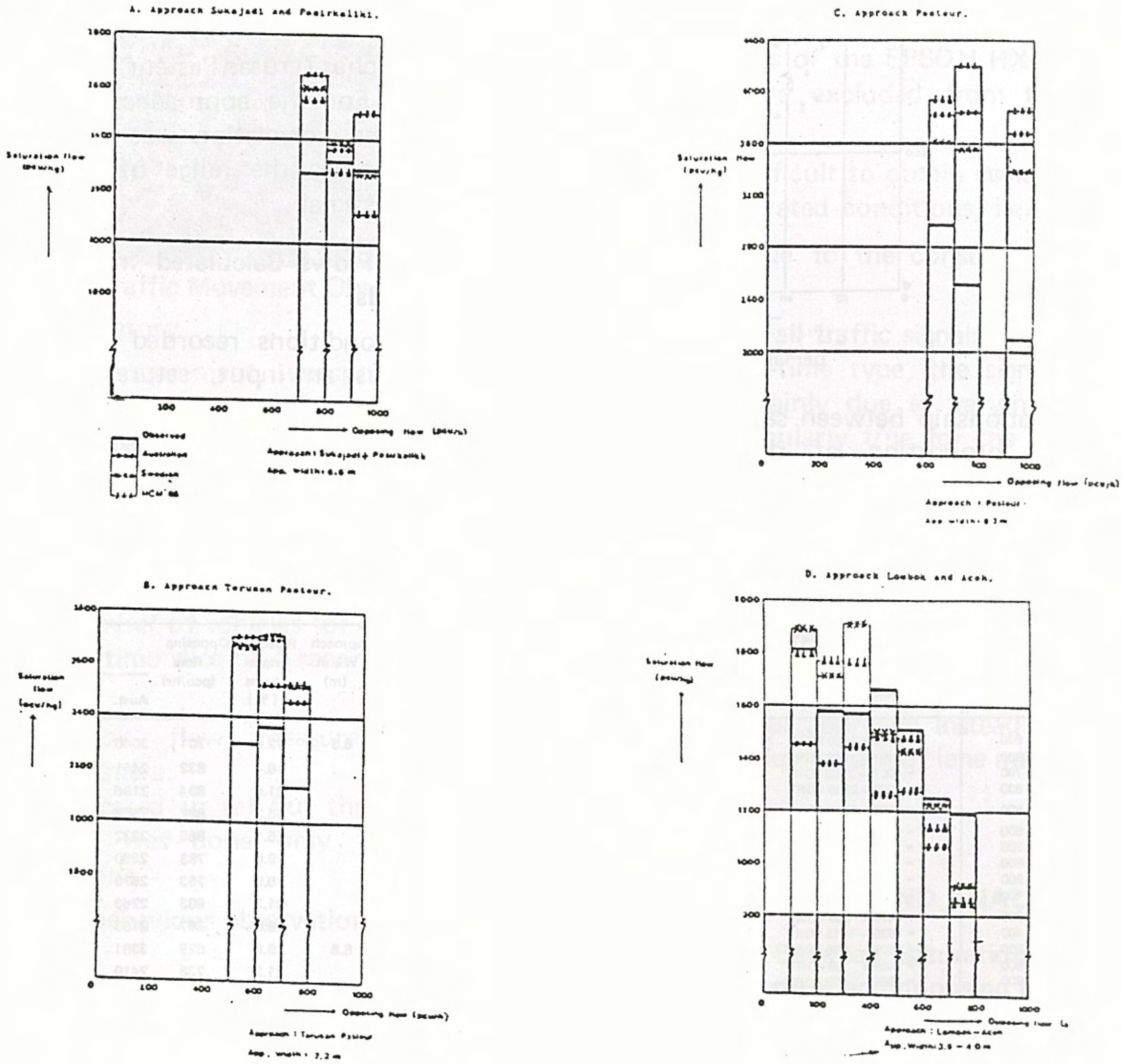


Fig. 5 — Comparison of observed and calculated saturation flows.

In the intersection of Jalan Sukajadi and Jalan Pasteur, the theoretical methods generally gave higher saturation flow values than the observed. The difference between the three theoretical methods was generally small (1.1–15.4 %).
The difference between the observed values and the average value of the three theoretical methods increased with increasing approach width:

Approach width	6.6 m : 0.7 – 15 %
	7.2 m : 12 – 17 %
	8.2 m : 27 – 73 %

For the intersection between Lombok and Aceh, with approach widths between 3.9 and 4.0 m, the Australian method gave lower values of saturation flow than the observations at all levels of opposing flow (−8.6 to − 28.6 %).

Saturation Flow Variation During The Green Time

During a green phase, saturation flow fluctuates due to the number of opposed right-turns. To analyse this fluctuation, saturation flows were measured for each time slice of 4 seconds, then plotted in graphs.

Saturation flow values calculated from the Swedish method were also illustrated in the graphs. See Figure 6 for a typical cycle taken from the observed data.

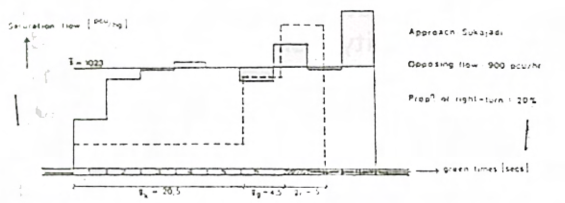


Fig. 6 — Saturation Flow Variation During The Green Time.

None of the observed cases seems to conform to theoretical pattern. Moreover, the observed saturation flow patterns showed that some vehicles discharged long after the appearance of the red signal. The longer the discharge time after the end of the green, the more traffic discharging in other phases is obstructed which may have to be considered. It was quite evident from site observations that the higher the opposing flow, the greater the number of vehicles crossing the stopline after the end of the green aspect.

Discharge Pattern Due To Traffic Composition

Indonesian traffic has a considerable motorcycle content which is usually not the case in Western traffic. This is belived to influence the discharge pattern of vehicles at the appearance of a green signal in both the opposing approaches. In additionts to varying opposing flows, the proportion of right-turns, the presence and location of a median and the composition of traffic waiting at the stop line, will also influence the discharge pattern. Diagrams shown in Fiugure 7 indicated this pattern. Motorcycles almost always used the beginning of the green signal to discharge whether they were the opposed right-turners or the opposing vehicles.

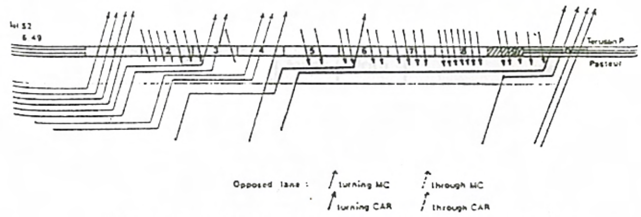


Fig 7 - Discharge pattern due to traffic composition. (From field observation)

The theoretical methods assume that at two-phase signalised intersections, priority is given to the opposing flow until an acceptable gap appears that can be used by the right-turning vehicles. Although a priority rule exists in Indonesia, it does not seem to be followed by drivers in conflict with opposed turns. This can be seen in the diagrams in Figure 7, which also show how Indonesian drivers behave at varying opposing flows, proportion of right-turns and type of vehicle used. The greater the opposing flow, the more the right-turning traffic is encouraged to discharge in the beginning of the green signal, and the longer the time after the end of green is used to discharge.

Similar circumstances occufred regarding the proportion of right-turns.

Determination of PCU Values for Motorcycle and Bus/Truck and Equations for Saturation Flows by Regression Analysis.

PCU values for motorcycle of 0.2 and bus/truck of 2.0 were assumed for through traffic; these were based on research by Djohar (1984). In order to assess the influence of opposed right-turning traffic, the PCU values of motorcycle and bus or truck were calculated from the observed data by regression analysis. See Table 3.

The pcu value of a motorcycle ranged from 0.22 to 0.64 and of bus or truck from 2.54 to 2.63. The higher the proportion of right-turns, the greater the pcu value of motorcycles. Equations for calculating saturation flow were also obtained through multiple regression analysis. These equations were varied regarding the number of

Table 3 – PCU values determined by regression analysis

Approach	Pcu value				
	A			B	
	M/C	B/T	r	M/C	r
Opposed conditions					
Sukajadi–Pasirkaliki	-0.45^{a}	0.49^{a}	–	-0.47^{a}	–
Terusan Pasteur	0.22	2.63	0.95	0.23	0.92
Pasteur	0.39	4.37	0.63	0.04^{a}	--
Median lanes :					
Sukajadi–Pasirkaliki	-0.24^{a}	-0.05^{a}	–	-0.22^{a}	–
Terusan Pasteur	0.64	2.54	0.69	0.64	0.65
Pasteur	0.02^{a}	3.60^{a}	–	0.24	0.26
Lombok–Aceh	0.32	1.13	0.40	0.31	0.42

variables such as width (W), proportion of right-turns (PORT), opposing flow (QOP) and proportion of right-turns in the opposing flow (OPRT). The results are shown in Table 4. Most of the equations show expected tendencies, i.e.

- saturation flow increased with an increase of width (positive sign);
- saturation flow decreased with an increase of proportion of right-turns (negative sign);
- saturation flow decreased with an increase of opposing flow (negative sign).

However no definite sign could be predicted for the proportion of right-turns in the opposing flow.

Table 4 – Equations for saturation flows determined by regression analysis

Approach	Variables				EQUATIONS
	W	PRT	QOP	OPPT	
All	x	x	x	x	S = 629 + 274 W – 156 PRT–0.29 QOP + 90 OPRT (r = 0.82)
All	x	x	x		S = 645 + 277 W – 123 PRT – 0.324 QOP (r = 0.82)
All	x		x		S = 633 + 273 W – 0.309 QOP (r = 0.82)

Note: W = Width of approach
PRT = Proportion of right-turns
QOP = Opposing flow
OPRT = Proportion of right-turns in the opposing flow

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Due to the large variation in saturation flow and the many variables involved, sufficient information could not be collected within the scope of the present project to obtain significant results other than for a limited number of cases.
2. Generally, good correlations were obtained between saturation flow, approach width and opposing flow. This was, however, not the case regarding the ratio of right-turns, which is an important factor in the theoretical models for estimation of saturation flow during opposed conditions.
3. Observations showed that discharge continued for a considerable time after the end of the green phase. This is not assumed in the theoretical models.
4. The field observations showed that the right-turning vehicles did not give way to opposing traffic, as assumed in the theoretical models. This was especially true for motorcycles which typically constituted nearly half of the flow of vehicles at the sites studied.
5. The pcu value of motorcycles during the opposed flow condition ranged from 0.22 at a low proportion of right-turns to 0.64 at a high proportion of right-turns.
6. Comparison between average observed and theoretical saturation flows showed a reasonable similarity for an approach width of 6.6 m. The theoretical methods however increasingly overestimated the saturation flow at higher approach widths.
7. The Australian method gave lower values of saturation than the observed at all levels of opposing flow in apporoaches having one lane.

Recommendations

For Indonesian traffic conditions, all calculations should be performed in pcu/hr due to the variation of traffic composition and the considerable motor-cycle content.

Research on the variation of pcu values at different conditions would be useful for capacity calculations. A major task in the immediate future is to determine the influence of different levels of opposing flows on the pcu values.

Further study of the influence of opposed right-turns on saturation flow, for a wide range of different conditions and sites would be desirable.

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Penulis:

Ir. Jany Agustin, M.Sc, Lulus Sipil UNPAR 1978, dan Sistem & Teknik Jalan Raya ITB/University College London, 1986. Bekerja di Bidang Konstruksi Pusat Litbang Jalan 1978-1985. Sejak 1986 aktif melakukan penelitian di Bidang Teknik Lalu Lintas dan Transportasi Pusat Litbang Jalan.