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Mixed Traffic Saturation Flows of Signalized Intersections in Motorcycle Dominant Cities

Vu Anh TUAN [a], Nguyen Dinh Vinh MAN [b]
[a,] *Department of Traffic and Transport, Vietamese-Germany University, Ho Chi Minh City, Vietnam*
[a] *E-mail: drtuan.va@vgtrc.vgu.edu.vn*
[b] *E-mail: ngvinhmancd@gmail.com*

Abstract: The objectives of this study are three folds: (1) Understanding the characteristics of traffic flows at signalized intersections in motorcycle dominated cities; (2) Examining influential factors to the saturation flow rate; (3) Developing rigorous models for better representation and calculation of saturation flow rate under the mixed traffic conditions. This study collected traffic data in Ho Chi Minh City to understand the unique characteristics of the mixed traffic flows at signalized intersections and attempted to develop saturation flow rate models based on regression techniques. The developed models consider the effects of a number of factors, including approach width, vehicle types, right-turn four-wheeled vehicles, and green time duration. A comparison with previous models shows the superior of the model in representing the mixed traffic flows at signalized intersections in Vietnam. The results can be useful for the design of signal control methods and intersection management.

Key Words: Regression, Saturation Flow Rate, Mixed Traffic, Signalized Intersection, Motorcycle Dominant City

1. INTRODUCTION

Saturation flow is one of the fundamental topics for traffic signal control and intersection management schemes. Currently, signalized intersections in developing countries like Vietnam are mostly designed and controlled by applying the guidelines developed for western countries like Germany, USA, France, and Japan. However, traffic conditions in developing countries are totally different; there are a huge number of motorcycles mixing with automobiles. Thus, a direct application of the guidelines may be not appropriate. Furthermore, there are a few studies on saturation flow for developing cities where motorcycles are dominating traffic flows.

The main purposes of this study are three-fold: (1) To understand the characteristics of traffic flows at signalized intersections in motorcycle dominated cities; (2) To determine influential factors to the saturation flow rate; and (3) To develop models of saturation flow rate reflecting the mixed traffic conditions.

This paper consists of the following parts. First, the introduction part provides the needs for this study, followed by the literature review that shows the essence of studies on the saturation flow in motorcycle dependent cities. Next, it introduces data collection procedure, including selection of intersections and observation methods. The study briefly present and discuss unique characteristics of traffic flows at the surved intersections. Subsequetly, it presents the development of saturation flow rate models for representing the traffic system in motorcycle dominated cities. Finally, it compares the developed model with the previous ones. The conclusion summaries the achievements of the study as well as the future works.

2. LITERATURE REVIEW

Factors to the saturation flow are usually specific to the local conditions. Thus, different countries would consider different factors for modeling the saturation flow rate to suit with their typical conditions. Table 1 describes three main influential factors (e.g., road conditions, traffic conditions, and weather and other conditions) to the saturation flow in a number of countries, including Vietnam.

Table 1 Influential factors to saturation flow at signalized intersection

Influence Factors	Descriptions	Guidelines							
		HBS 2001	HCM 2000	TRRL 67	ARRB 123	TAC 2008	JTCR	IHCM 1997	MHCM
Road Conditions	Approach width	●	●	●	●	●	●	●	●
	Gradient	●	●	●	●	●	●	●	●
	Intersection geometry	●							
Traffic Conditions	Vehicle type	●	●		●		●		●
	Turning vehicle		●	●	●	●	●	●	
	Pedestrian crossing	●	●		●	●			
	Green time					●			
Weather and Other Conditions	Weather			●	●			●	
	Parking		●			●			
	Bus stop		●		●	●			
	Lane utilization		●	●	●				

2.1 Studies in Car Dominant Societies

There are two typical guidelines, namely American Highway Capacity Manual (HCM, 2000) and German Highway Capacity Manual (HBS, 2001). Many developing countries like Indonesia and Malaysia often utilize or rely on the American HCM (2000) in calculating saturation flow rate. Under the HCM (2000), the saturation flow rate is the number of vehicles per hour that can be accommodated by a group of lanes assuming that the green phases were displayed 100 percent of the time. There are two main components in the saturation flow rate formula, including the base saturation flow rate per lane, S_0 (often S_0=1900 pc/h/l), and the number of lanwes in a lane group, *N*. In addition, there are eleven adjustment factors in the formula (e.g., approach gradient, lane width, parking activity) as these factors would influence the value of the saturation flow. In Indonesian Highway Capacity Manual (1997), there are six adjustment factors to the saturation flow, including the ones related to city size, side friction, gradient, parking, right-turn, and left-turn. In Malaysian HCM, there are four adjustment factors, including lane width, gradient, type of area, and vehicle composition. The base saturation flow rate per lane is given the same value with the value of HCM (2000), S_0=1900 (pc/h/l).

In German Highway Capacity Manual (HBS, 2001), the formula is based on three components, including the base saturation flow rate and the two highest factors among the five adjustment factors. The base saturation flow value is the ratio of 3,600 s and the saturation headway. The five adjustment factors include lane width, turning radius, gradient, pedestrian traffic, weather conditions, and local characteristics.

2.2 Studies in Motorcycle Dominant Societies

In Vietnam, there were several studies on the saturation flow rate. For example, Tho (2003) conducted a study in Da Nang and Hanoi city. In the study, the saturation flow rate was divided into 2 groups; the first group had the flow value of 6828-9720 vphg for the approach width of 4-7 m and the second one had the flow value of 10782-16330 vphg for the approach width 7-10 m. Hien and Montgomery (2007) conducted surveys at 12 intersections with lane width varying from 4 m to 13 m. The authors applied the regression method to develop the calculation formula taking into account of lane width, turning vehicles, and turning radii. Recently, Minh and Binh (2009) proposed a saturation flow formula for Ho Chi Minh City. The regression model was developed taking the effect of lane width.

The aforementioned methods use passenger car unit (PCU) as a standard unit. This is only suitable when car share in the traffic flow is so high that its behavior presents the traffic characteristics, as depected in the car dominat societies. In fact, in developing countries, particularly in Vietnam, Indonesia and Malaysia, there are an extremely high share of motorcycles in the traffic, thus converting motorcycle to car for the calculation seems unsuitable. The moving behavior of motorcycles is dominating the traffic flow characterstics. This study proposes to use motorcycle equivalent unit (MCU) for the calculation and attempts to investigate the effects of important factors, such as vehicle type (e.g., the percentage of passenger car, bus, and HGV), approach width, green time duration, and right-turn vehicle. Of course, there are other factors that may affect the saturation flow rate, such as the left-turn vehicles, approach gradient, weather conditions, crossing pedestrains, ect. However, due to time limitation, this study focuses on the four important factors first. In future, the other factors will be taken into account to further improve the calculation methods.

3. DATA COLLECTION

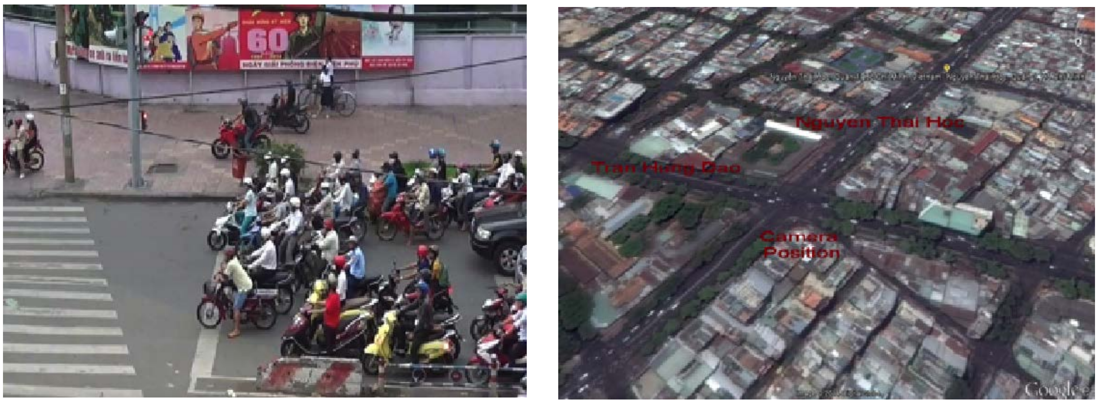
This section briefs methods for traffic observation and traffic data collection. Traffic streams are observed by video cameras at seven intersections in Ho Chi Minh City, representing different conditions, such as traffic composition, signal cycle length, approach width, etc (Table 2 and Figure 1). The sample size of each intersection is scientifically determined to get enough samples for analysis and calculation.

3.1 Observation Method

Equipment are used for observation includes a camcorder, a stopwatch, a measuring wheel, and a computer. The camcorder is placed at a high position, such as on a roof of a building located near the intersection, or at a visible place to produce the best quality videos for traffic counting as well as to advoid any suspicion of road users. The stopwatch is used in parallel for time recording if the traffic lights is invisible to the camcorder. The measuring wheel is used to measure approach widths of the intersections. The video clips are are analyzed for traffic counts in the laboratory using the computer.

(1) Ton Duc Thang – Nguyen Huu Canh Intersection (pictured Ton Duc Thang approach)

(2) Truong Chinh – Pham Van Bach Intersection (pictured Truong Chinh approach)



(3) Nguyen Thai Hoc – Tran Hung Dao Intersection (pictured Nguyen Thai Hoc approach)

(4) Hanoi Highway – Tay Hoa Intersection (pictured Hanoi Highway approach)


(5) 550 Intersection (pictured 743 approach)


(6) Dien Bien Phu – Hai Ba Trung Intersection (pictured Dien Bien Phu approach)


(7) An Duong Vuong – Nguyen Tri Phuong Intersection (pictured An Duong Vuong approach)

Figure 1 Illustration of the seven surveyed intersections and approaches

3.2 Selected Intersections

For good video observation, an intersection is chosen based on the following requirements:

- It has no uphill nor downhill gradient.
- The approaches should have no bus stop nearby.
- There is a good place to locate the camcorder (no visionary obstructions).
- The approaches should have limited pedestrian crossing flows.
- It should have no sharp curves nor unusual geometry conditions.

For the purpose of analysis, selected intersections shall have the following characteristics:

- Located in the main areas of the city center.

- Usually reach to the saturation state in rush hours.
- Have median to avoid the influence of the opposite traffic flows.

Table 2 presents a list of selected intersections with physical characteristics. It is noted that in Vietnam the traffic signal cycles are normally fixed.

Table 2 Physical characteristics of surveyed intersections

No.	Approach Name	Intersection Name	Lane Width (m)	Traffic Phase (s)		
1	Ton Duc Thang	Ton Duc Thang - Nguyen Huu Canh	4.50	51 s	3	68 s
2	Truong Chinh	Truong Chinh - Pham Van Bach	9.00	81 s	3	36 s
3	Nguyen Thai Hoc	Nguyen Thai Hoc - Tran Hung Dao	11.5	61 s	3	62 s
4	Hanoi Highway	Hanoi Highway - Tay Hoa	7.50	51 s	3	50 s
5	743 Approach	550 Intersection	11.0	45 s	3	36 s
6	Dien Bien Phu	Dien Bien Phu - Hai Ba Trung	12.5	53 s	3	64 s
7	An Duong Vuong	An Duong Vuong - Nguyen Tri Phuong	8.00	47 s	3	42 s

3.3 Count Method

For calculating car saturation traffic flow, time inveral for traffic count is often set 3 s or 6 s. However, this method seems not suitable in motorcycle dominant cities because motorcycle length is much shorter than car length; given the same speed, it takes less time than for a motorcycle to pass the stop line than a car. Within an interval of 3 s or 6 s, the number of motorcycles passed the stop line are quite large, so it is hard to count and also affects the accuracy of the counting result. This research proposes count interval be 2 s.

3.4 Sample Size

Based on HCM (2000), 15 is a minimum number of samples or observations for the saturation flow research. TRRL (1993) proposed the sample size requirement be 25. The sample size should be based on road conditions. This study applies the sample size determination formula developed in Traffic Engineering (the 4th Edition).

$$N \geq \frac{1.96^2 \times s^2}{e^2} \qquad (1)$$

Where:

N: sample size
1.*96*: corresponds to 95% confidence
s: the standard deviation
e: the tolerance

Table 3 Sample Size by Intersection

No.	Approach	Intersection	Required samples	Actual samples
1	Ton Duc Thang	Ton Duc Thang – Nguyen Huu Canh	18.5	30
2	Truong Chinh	Truong Chinh – Pham Van Bach	9.5	30
3	Nguyen Thai Hoc	Nguyen Thai Hoc – Tran Hung Dao	14.9	40
4	Hanoi Highway	Hanoi Highway – Tay Hoa	20.5	25

5	743 Approach	550 Intersection	7.9	25
6	Dien Bien Phu	Dien Bien Phu – Hai Ba Trung	5.5	27
7	An Duong Vuong	An Duong Vuong – Nguyen Tri Phuong	8.2	30
		Total		**207**

4. CHARACTERISTICS OF TRAFFIC FLOWS AT SURVEYED INTERSECTIONS

This section presents general characteristics of the saturation flows at the studied intersections for a first and basic understanding. Based on this, the modeling of the saturation flow rate in the subsequent section can be established.

4.1 Truong Chinh Approach

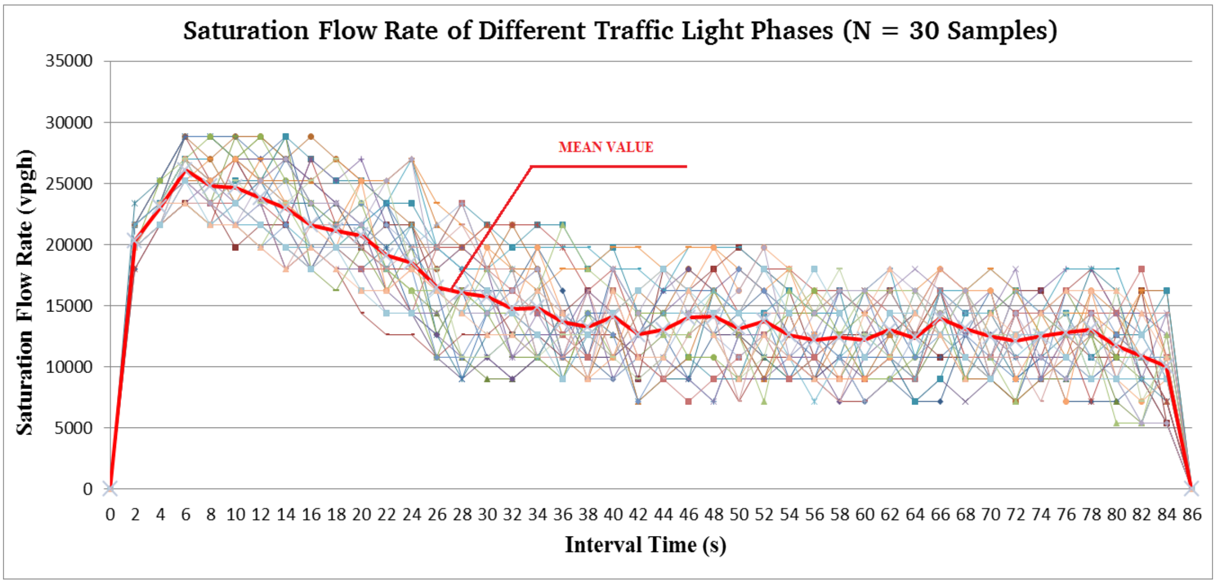


Figure 2 Saturation Flows on Truong Chinh Approach (Approach Width = 9.0 m)

As seen in Figure 2, during the first 6 seconds, the saturation flow rate increases sharply and it reaches the peak of above 27,000 (mpgh). Between the 6th second to the 26th second, the figure drops to 16,500 (mpgh). The saturation flow rate fluctuates slightly for the next 58 seconds, and then drops to zero in the 86th second.

4.2 Ton Duc Thang Approach

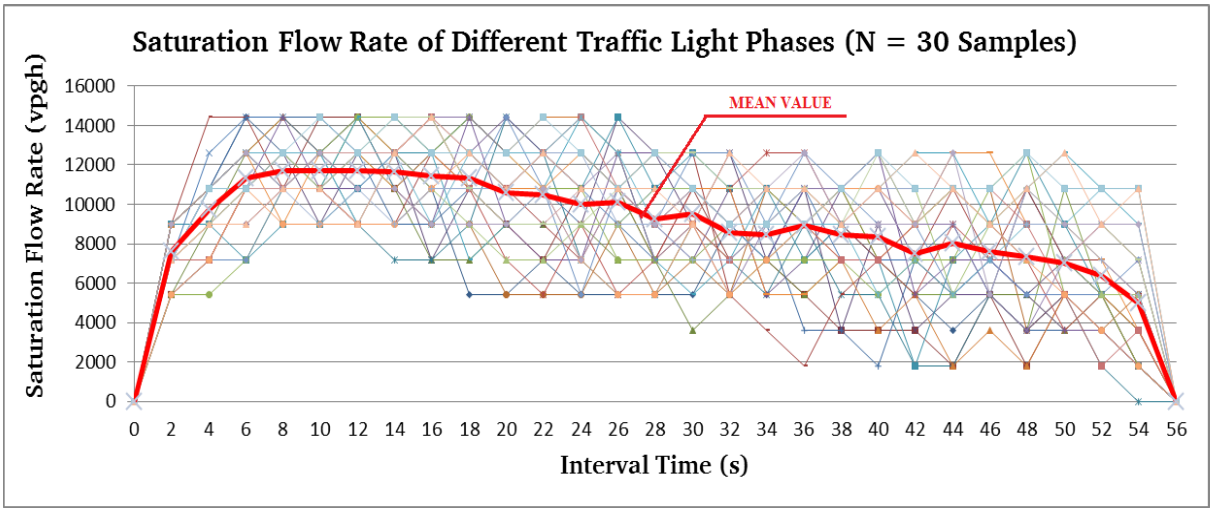


Figure 3 Saturation Flows on Ton Duc Thang Approach (Approach Width = 4.5m)

As observed, in the first 8 seconds, the rate shoots up and reaches the peak of 11,700 (mpgh). In the next 4 seconds, the figure is remained stably at 11,700 (mpgh). From the 12^{th} second to the 52^{nd} second, the rate declines steadily to 6,360 (mpgh). The figure continues to fall sharply over the next 2 seconds until it becomes zero.

4.3 Hanoi Highway Approach

On Hanoi Highway approach, there are some signal phases that have motorcycles only. In some phases, there are also buses in the flow. It is interesting to compare the flow rates of the two cases.

- *Case of Motorcycle Only Flows*

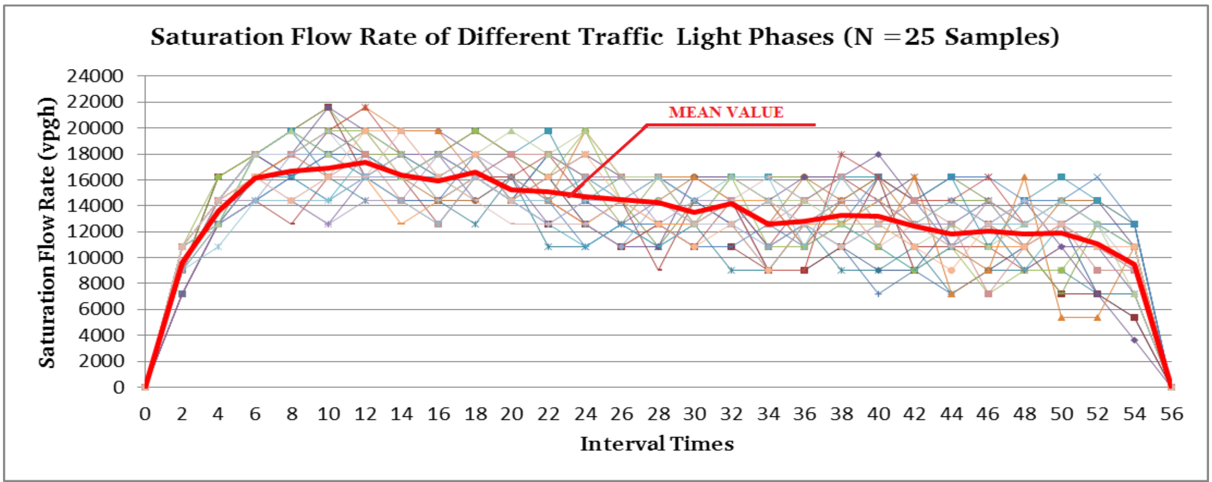


Figure 4 Saturation Flows on Hanoi Highway Approach (Approach Width = 7.5m) – The case of Motorcycle Only Flows

The saturation flow rate increases sharply and reaches the highest value at above 17,000 (mpgh) in the 12^{th} second. After that, it drops steadily to around 9,500 (mpgh) before going down to zero in the 56^{th} second.

- *Case of Motorcycle and Bus Mixed Flows*

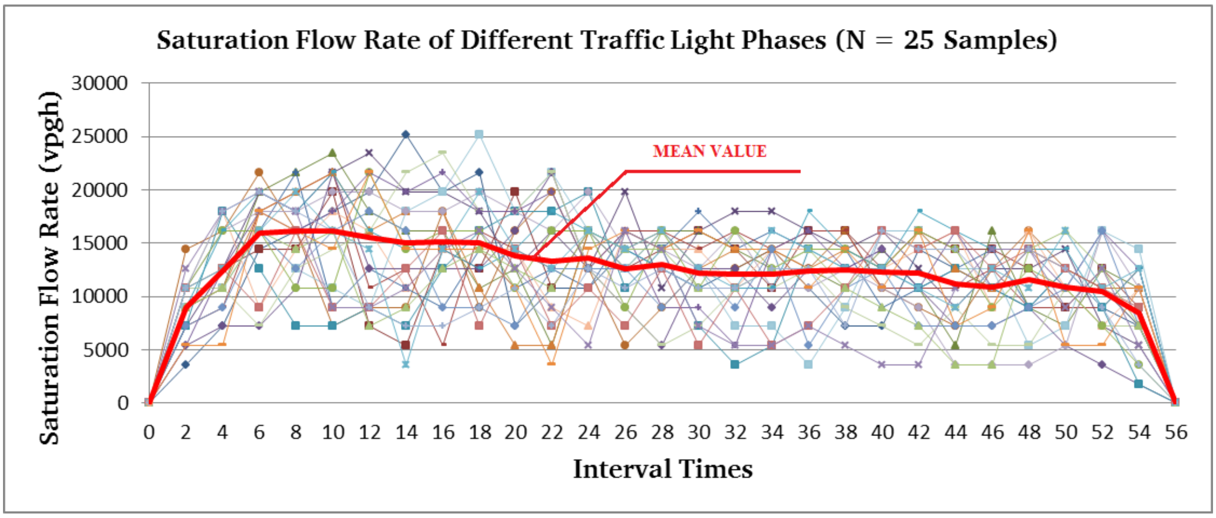


Figure 5 Saturation Flows on Hanoi Highway Approach (Approach Width = 7.5m) – The case of Motorcycle and Bus Mixed Flows

During the first 6 seconds, the saturation flow rate increases sharply from 0 to around 14,500 (mpgh). Then, it fluctuates for the next 48 seconds until it becomes zero. Comparing Figure 4 and 5, it seems that the presence of buses would contribute to a sigficant drop in the saturation flow rate.

4.4 Nguyen Thai Hoc Approach

On Nguyen Thai Hoc approach, there are signal phases with flows of motorcycles and passenger cars only and there are some phases with the presence of buses and passenger cars mixed with motorcycle flows. It is also interesting to compare the two cases.

- *Case of Motorcycle and Car Mixed Flows*

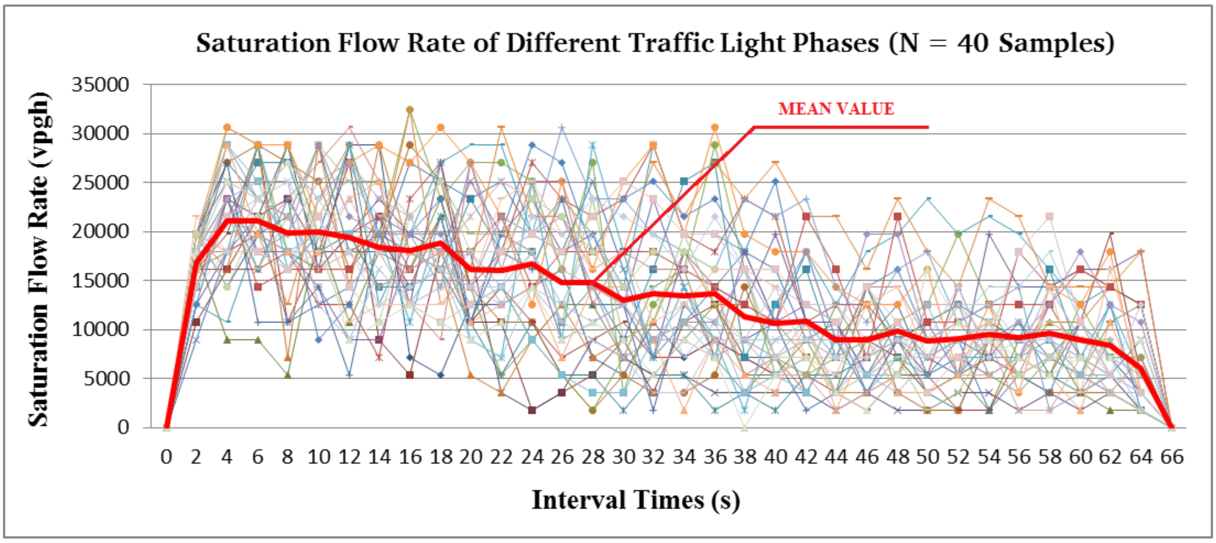


Figure 6 Saturation Flows on Nguyen Thai Hoc Approach (Approach Width = 11.5m) – The case of Motorcycle and Car Mixed Flows

The saturation flow rate increases sharply and reaches the highest value at 26,730 (mpgh) in the 6th second. Between the 6th second and the 42nd second, it drops sharply to 15,525 (mpgh).

Then, it fluctuates slightly for the next 16 seconds, and moving to zero in the 66th second.

- *Case of Motorcycle, Car, and Bus Mixed Flows*

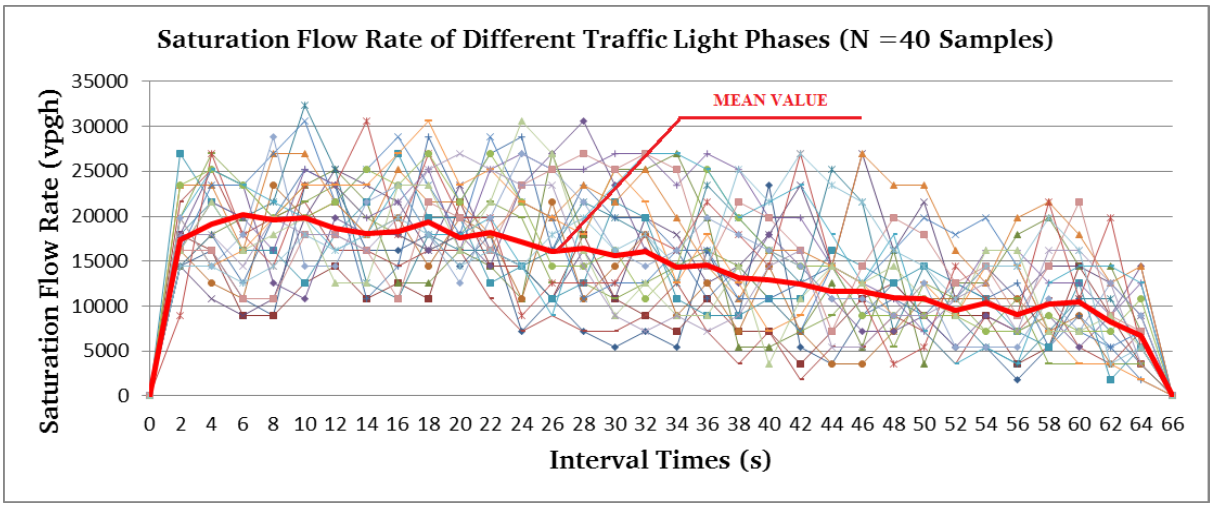


Figure 7 Saturation Flows on Nguyen Thai Hoc Approach (Approach Width = 11.5m) – The case of Motorcycle, Car, and Bus Mixed Flows

The saturation flow rate increases sharply and reaches the highest value at around 26,000 (mpgh) in the 12th second. Then, it fluctuates significantly for the next 52 seconds, and moving down to zero in the 66th second. The large fluctuations may refect the effect of buses on the flow rate.

4.5 Approach 743

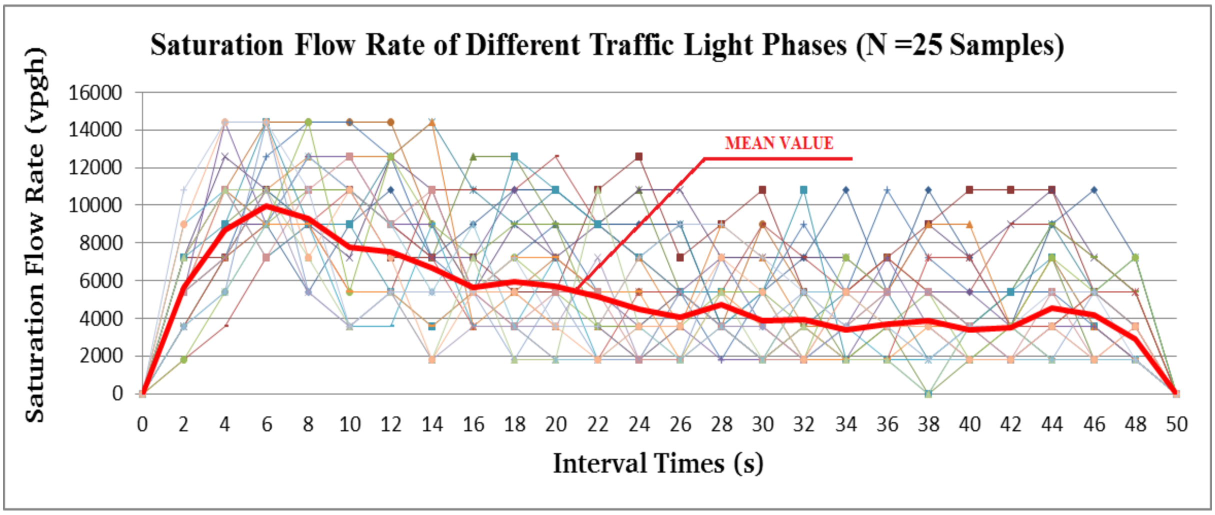


Figure 8 Saturation Flows on Approach 743 (Approach Width = 11.0m)

As can be seen clearly, the saturation flow has some typical characteristics. The highest value is 20,375 (mpgh) in the 12th second. There is a wide fluctuation in the figure due to the presence of trucks or heavy vehicles (HGV).

4.6 An Duong Vuong Approach

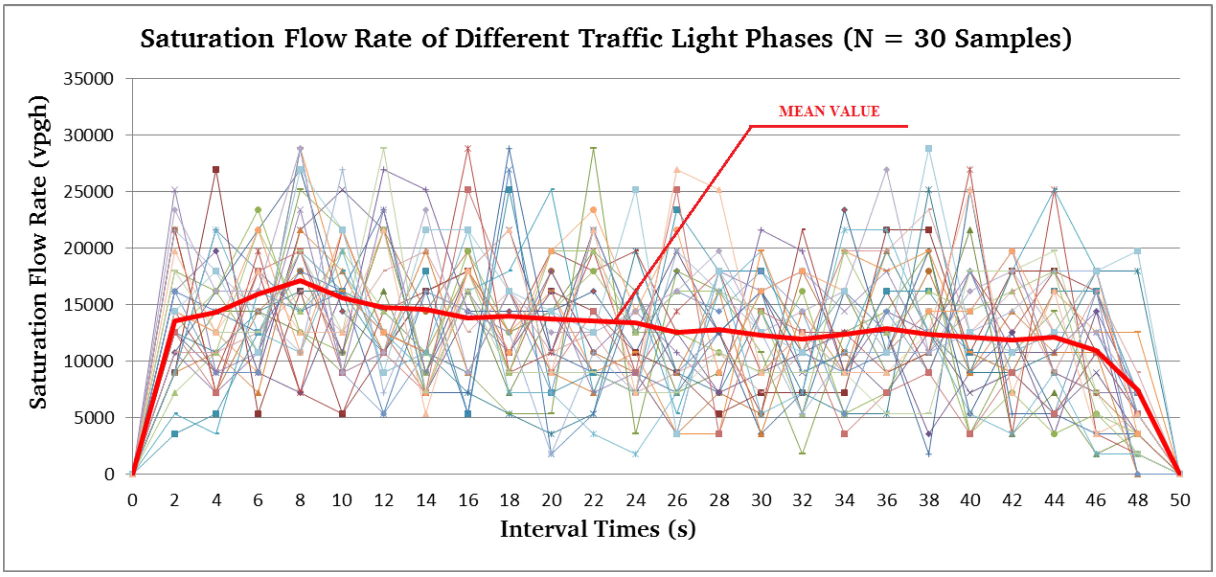


Figure 9 Saturation Flows on An Duong Vuong Approach (Approach Width = 8.0m)

In the first 2 seconds, the saturation value reaches 14,000 (mpgh), and it goes up to the peak of about 17,000 (mpg). Afterwards the saturation value decreases slightly until the end of the phase.

4.7 Dien Bien Phu Approach

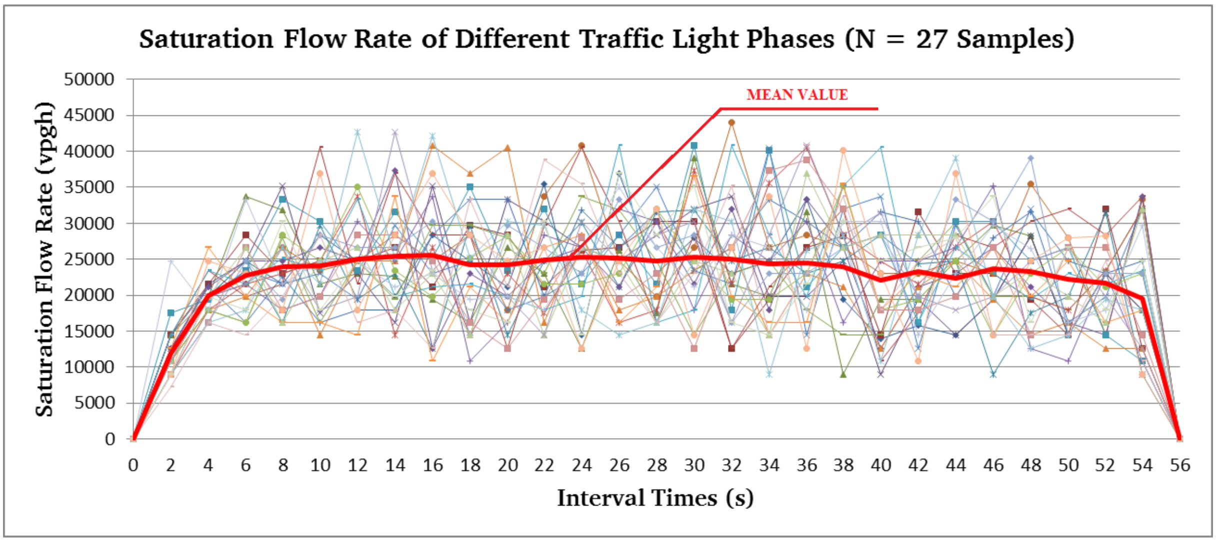


Figure 10 Saturation Flows on Dien Bien Phu Approach (Approach Width = 12.5m)

In the first 6 seconds, the saturation value increases sharply to approximately 23,000 (mpgh), and the saturation value has a slight fluctuation until the end of the phase.

5. SATURATON FLOW RATE MODELS

As mentioned, the saturation flow rate may be affected by many factors, such as approach width, heavy vehicles, longitudinal gradient, parking, weather conditions, right turns, left turns, traffic behaviors, crossing of pedestrians, etc. In this study, due to time limits, it focuses on 4 main factors, namely approach width, vehicle type, duration of green time, and right turns. At a signalized intersection, the saturation flow value increases when the approach is wider. In the motorcycle dominant societies, passenger car, bus, and HGV can be seen as the large vehicles as compared to motorcycle. The appearance of such large vehicles would affect the saturation flow value. If the green time s too long, the drivers tend to reduce the speed of their vehicles, this would reduce the value of the saturation flow rate. The right-turning activities affect directly to the traffic flow, especially to motorcycles. To take into account of those factors, the study proposes the following equation for calculating saturation flow rate:

$$S = S_W * f_V * f_G * f_R \tag{2}$$

Where:
S_W = Saturation flow rate of motorcycles depending on the approach width
f_V = Adjustment factors of different vehicle types (4-wheeler)

$$f_V = f_{PC} * f_{Bus} * f_{HGV}$$

f_G = Adjustment factor of green time duration
f_R = Adjustment factor of right turning vehicle

Subsequent sections present the determination of the factor effects.

5.2.1 Saturation Flow Rate Depending on The Approach Width

The saturation flow rate depending on the approach width (S_W) is analyzed by applying different models and based on the traffic data. It is noted that due to a time limit, the traffic data were collected at only three intersection approaches of different width. Table 4 shows elevent different models. Table 5 illustrates a model summary and parameter estimation of the different models. Clearly, Quadratic regression model, Cubic regression model, Logistic regression model, Growth regression model, and Exponential regression model have R Square and F value in the highest group. Applying the five different models to compute the saturation flow rate for different approaches, the results are showed in Table 6. It shows that the Logistic regression model has biggest and smothest values than the other models. Thus, this model is choosen for analysis and calculation.

Table 4 Regression models of Saturation flow rate depending on the approach width (N = 90 Samples)

Model	Formula	Adjusted R Square
Linear Regression Model	S_W = -351.838+ 2508.399*W	0.93
Logarithmic Regression Model	S_W = -12627.125+ 15668.899*ln(W)	0.90
Inverse Regression Model	$S_W = 31811.645 - \frac{93640.123}{W}$	0.86
Quadratic Regression Model	S_W = 24655.568-5706.997*W + 617.467*W^2	0.95
Cubic Regression Model	S_W = 15724.351-1539.096*W + 29.403*W^3	0.95
Compound Regression Model	S_W = 5642.662*1.165^W	0.95

Power Regression Model	$S_W = 2633.767 * W^{0.962}$	0.94
S-Curve Regression Model	$S_W = e^{10.611 - \frac{5.79}{W}}$	0.91
Growth Regression Model	$S_W = e^{8.638 + 0.153W}$	0.95
Exponential Regression Model	$S_W = 5642.662 * e^{0.153W}$	0.95
Logistic Regression Model	$S_W = \frac{1}{0.000177 * 0.858^W}$	0.95

Note: *W* = Approached lane width (m)

Table 5 Model Summary and Parameter Estimates

Dependent Variable: SFR									
Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.965	1132.090	1	84	.000	-351.838	2508.399		
Logarithmic	.949	766.031	1	84	.000	-12627.125	15668.899		
Inverse	.928	525.165	1	84	.000	31811.645	-93640.123		
Quadratic	.974	761.707	2	83	.000	24655.568	-5706.997	617.467	
Cubic	.974	761.707	2	83	.000	15724.351	-1539.096	.000	29.403
Compound	.977	1780.863	1	84	.000	5642.662	1.165		
Power	.970	1337.920	1	84	.000	2633.767	.962		
S	.957	907.217	1	84	.000	10.611	-5.790		
Growth	.977	1780.863	1	84	.000	8.638	.153		
Exponential	.977	1780.863	1	84	.000	5642.662	.153		
Logistic	.977	1780.863	**1**	**84**	**.000**	**.000177**	**.858**		
Independent variable is W.									

Table 6 Saturation Flow Rates calculated by Different Formulas

Lane Width (Meter)	**Saturation Flow Rate (vpgh)**				
	Quadratic Model	**Cubic Model**	**Exponential Model**	**Growth Model**	**Logistic Model**
3.5	12245.05	11598.17	9639.37	9638.30	9656.53
4.5	11477.79	11477.77	11233.00	11231.75	11254.70
7.5	16585.61	16585.52	17776.12	17774.14	17818.54
9	23307.42	23307.27	22361.84	22359.35	22420.29
11	36592.11	37929.69	30366.98	30363.61	30455.56
11.5	40685.11	42743.03	32781.22	32777.58	32879.33
12.5	49797.32	53913.39	38200.78	38196.53	38320.89

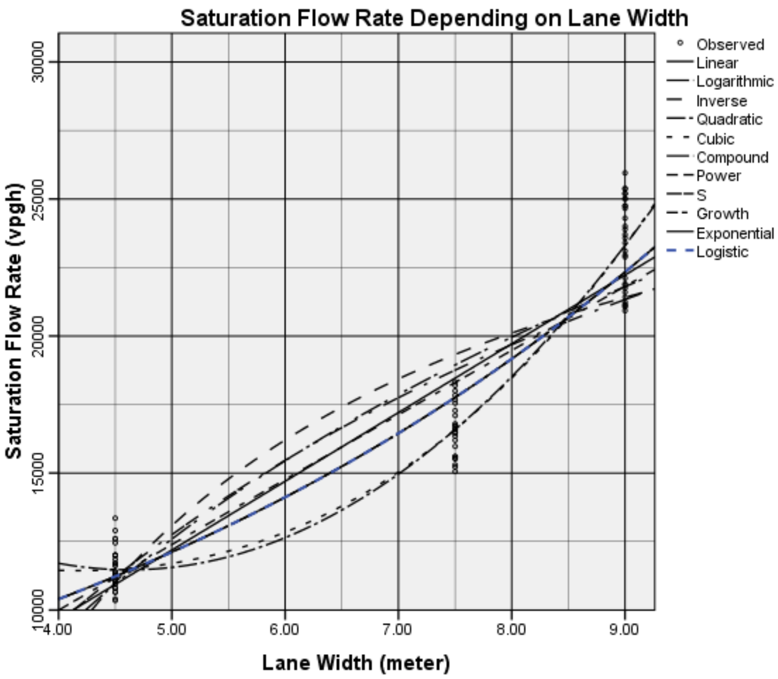


Figure 11 Saturation Flow Rates calculated by Different Formulas

5.2.2 Adjustment Factors of Different Vehicle Types

The impacts of passenger cars, buses, and HGV on the motorcycle flow are treated by individual adjustment factors, f_{PC}, f_{Bus}, and f_{HGV}, respectively. The impacts of such big vehicles are illustrated in Figures 5, 6, 7, and 10. In fact, the maximum percentage of buses is 20%. Figure 12 depicts adjustment factor for bus to 20% and passenger car and HGV to 100%. The adjustment factors are estimated by SPSS software with the sample size for bus is 55 samples, passenger car 70 samples, and HGV 30 samples. To account for the effect of each vehice type, observations are selectively done on the approaches that have only motorcycles and vehicles of the type of concern.

Formulas of the adjustment factor are shown in Equation 3, 4 and 5 below.

$$f_{Bus} = \frac{1}{1.0175 * 1.0265^{\mathrm{PB}}} \tag{3}$$

$$f_{PC} = \frac{1}{1.01 * 1.004^{\mathrm{PPC}}} \tag{4}$$

$$f_{HGV} = \frac{1}{1.0124 * 1.01^{\mathrm{PH}}} \tag{5}$$

Where:

- *PB* = Percentage of Bus
- *PPC* = Percentage of Passenger Car
- *PH* = Percentage of HGV

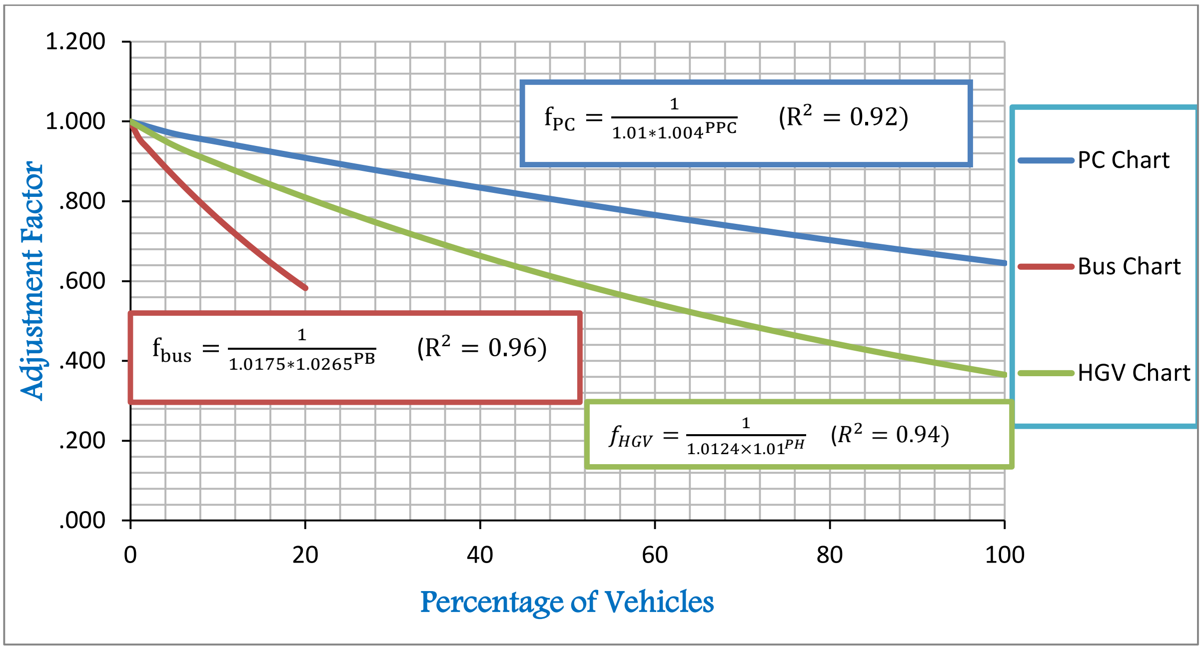


Figure 12 Passenger Car, Bus and HGV Adjustment Factors

5.2.3 Adjustment Factor of Green Time Duration

Observations at different intersection approaches show that the length of green time may have influences on the saturation flow rate. Figure 2, 3 and 4 depict the changes of traffic volumes over the green time length. As observed, in case of a very long green time, the traffic volume on the Truong Chinh approach reaches the maximum value (over-saturated) at the 22-24th second of the green time length, then it suddently drops to a lower saturated level until the 52-54th second, and then starts decreasing steadily after the 54th second. This phenomenon can be explained by the queueing behavior. Usually, the first arrival vehicles try to queue extremely tightly, especially motorcycles trying to fill in every small empty space, then the density becomes lower as the distance from the stop line increases. Figure 3 and Figure 4 are typical examples of the influence of the green time length on the saturation flow rate. Therefore, the adjustment factor of green time should be derived for 3 groups as follows:

- Group 1: $0 < \Delta t \leq 24$ seconds
- Group 2: $24 < \Delta t \leq 54$ seconds
- Group 3: $\Delta t > 54$ seconds

So the adjustment factor of the green time is a ratio between the basic saturation flow value and the corresponding saturation flow value based on lane width.

Table 7 Basic Characteristics of the Three Approaches

Approach Leg	Approach Width (m)	Green Time Duration (s)	S_w (vpgh)
Ton Duc Thang	4.5	54	11255
Hanoi Highway	7.5	54	17819
Truong Chinh	9.0	84	22421

Table 8 Calculated Green Time Adjustment Factors

ΔT (Second)	Green Time Adjustment Factor (f_G)		
	Ton Duc Thang	Hanoi Highway	Truong Chinh
$0<\Delta t \leq 24$	0.95	0.98	1.01
$24 <\Delta t \leq 54$	0.81	0.83	0.79
$\Delta t> 54$	-	-	0.70

Adjustment Factor of Green Time Length

According to the above calculation, the three approaches have the same adjustment factors in the first two groups. Therefore, the adjustment factors of the green time interval of the first two groups would be calculated by the mean value of the three approaches with the according time intervals. The adjustment factor of the last group would be computed based on Truong Chinh approach. Table 9 presents proposed adjustment factors of green time length.

Table 9 Proposed Green Time Adjustment Factor

Δt	f_G
$0<\Delta t \leq 24$	0.98
$24 <\Delta t \leq 54$	0.81
$\Delta t> 54$	0.70

5.2.4 Adjustment Factor of Right-Turn Four-Wheeled Vehicles

The right-turn adjustment factors are used to reflect the effect of four-wheeled vehicles (e.g., passenger car, bus, and HGV) on motorcycles in the mixed traffic. The picture below depicts the impacts of right-turning on the movement of motorcycles on Nguyen Thai Hoc approach.

Figure 13 Right-turn four-wheeled vehicles blocking the through traffic stream

The right-turn adjustment factor depends on the proportion of four-wheeled vehicles, particularly the higher the right-turn vehicle proportion the lower the adjustment factor. In case the percentage of right-turn vehicles is equal or less than 1%, there would be no effect on the saturation flow value. Based on about 30 observations, several models are estimated and the exponential regression model (Figure 14) is the best one.

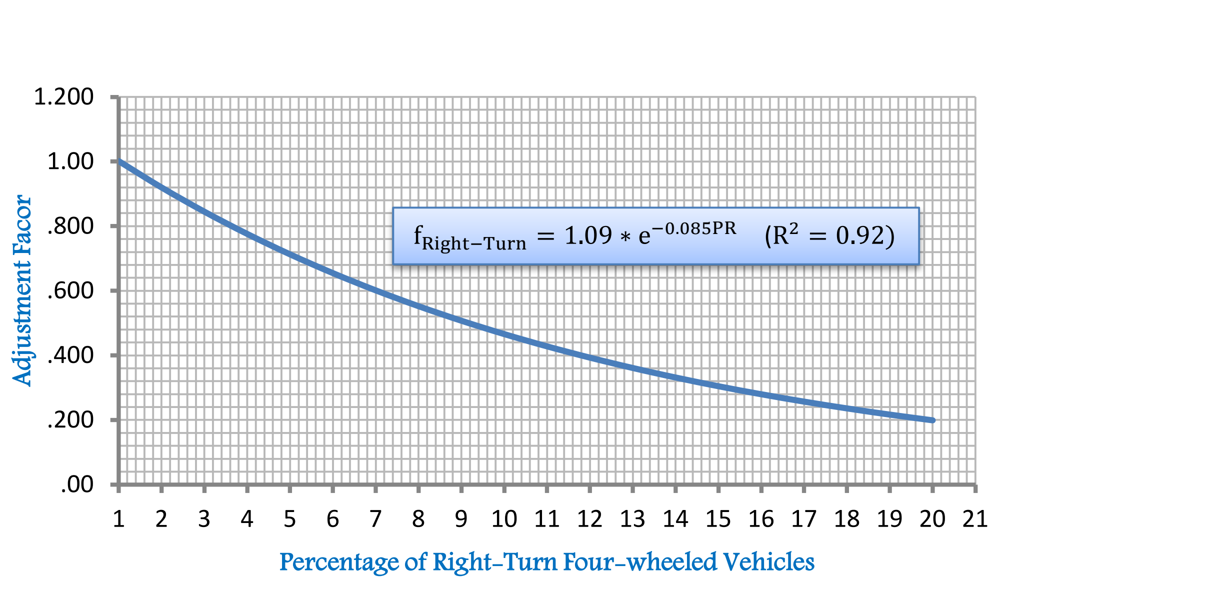


Figure 14 Right Turns Adjustment Factor Graph

The adjustment factor of right-turn vehicles on the saturation flow of motorcycle traffic flow can be calculated according to Table 10.

Table 10 Right-Turn Four-Wheeled Vehicle Adjustment Factor (N = 30 Samples)

Right Turns Adjustment Factor	$PR \le 1\%$	$f_R = 1$
	$PR > 1\%$	$f_R = 1.09 * e^{-0.085PR}$

Note: *PR* = Percentage of Right-Turn Four-Wheeled Vehicles

5.2.5 Saturation Flow Formula for Motorcycle Dominant Cities

Finaly, an equation for calculating saturation flow rate of an approach is derived as follow:

$$S = \frac{1}{0.000177 * 0.858^W} * f_V * f_G * f_R \tag{6}$$

Where:

W = Approach width (m)
f_V = Adjustment factors of different vehicle types (4 wheeler):

$$f_V = f_{PC} * f_{Bus} * f_{HGV} \tag{7}$$

f_G = Adjustment factor of duration of green time
f_R = Adjustment factor of right-turn vehicles (4 wheeler)

Table 11 Adjustment Factors to Saturation Flow Rate

Influential Condition		Adjustment Factor	Note
Heavy Traffic Adjustment Factor	Bus's factor	$f_{Bus} = \frac{1}{1.0175 * 1.0265^{PB}}$	*PB* = Percentage of Bus
	Passenger Car's Factor	$f_{PC} = \frac{1}{1.01 * 1.004^{PPC}}$	*PPC* = Percentage of Passenger Car
	HGV's factor	$f_{HGV} = \frac{1}{1.0124 * 1.01^{PH}}$	*PH* = Percentage of HGV
Green Time Duration Adjustment Factor	$0<\Delta t \leq 24$	$f_G = 0.98$	Δt = Green Time Interval (second)
	$24 <\Delta t \leq 54$	$f_G = 0.81$	
	$\Delta t > 54$	$f_G = 0.70$	
Right-Turn Four-Wheeled Vehicle Adjustment Factor	$PR \leq 1\%$	$f_R = 1$	*PR* = Percentage of Right-Turn Four-Wheeled Vehicles
	$PR > 1\%$	$f_R = 1.09 * e^{-0.085PR}$	

6. COMPARISON OF SATURATION FLOW MODELS

To evaluate the established formula, the formulas of the previous studies in motorcycle dominant cities are used to check the errors with the observed saturation flow rate, including the formulas of (Minh.C.C, 2003), (Hien.Nguyen, 2007), and (Tho.P.C, 2003). Dien Bien Phu Approach (at Dien Bien Phu – Hai Ba Trung Intersection) is selected for the comparision of fomulars. The results are presented in Table 12.

Table 12 Comparison of Saturation Flow Models for Mixed Traffic

Cycle No.	ΔT	Observed SFR	Developed Formula (this study)	Error (%)	C.C.Minh's	Error (%)	Hien Nguyen's	Error (%)	Tho.P.C's	Error (%)
1	48	26831,25	27630,20	2,98	34614,26	29,01	20337,13	-24,20	20412,5	-23,92
2	48	27015,75	27885,22	3,22	34614,26	28,13	28467,00	5,37	20412,5	-24,44
3	44	26467,36	27710,62	4,70	34614,26	30,78	18711,16	-29,30	20412,5	-22,88
4	26	27123,23	27843,76	2,66	34614,26	27,62	21869,81	-19,37	20412,5	-24,74
5	22	32184,00	33745,70	4,85	34614,26	7,55	19812,62	-38,44	20412,5	-36,58
…	…	…	…	…	…	…	…	…	…	…
25	24	31071,00	32456,18	4,46	34614,26	11,40	28467,00	-8,38	20412,5	-34,30
26	28	27789,43	27062,16	-2,62	34614,26	24,56	21869,81	-21,30	20412,5	-26,55
27	24	32293,50	33815,01	4,71	34614,26	7,19	28467,00	-11,85	20412,5	-36,79
28	72	24574,50	24400,42	-0,71	34614,26	40,85	23633,02	-3,83	20412,5	-16,94
29	66	24317,45	25034,03	2,95	34614,26	42,34	26020,63	7,00	20412,5	-16,06
30	56	24189,43	24879,94	2,85	34614,26	43,10	25474,97	5,31	20412,5	-15,61
31	56	24139,29	24050,71	-0,37	34614,26	43,39	22129,54	-8,33	20412,5	-15,44
Mean Errors				**-0,34**		22,01		15,77		-28,05

It shows that the formula developed by this research has the highest accuracy (error .34%), and the formula of Tho (2003) has the lowest accuracy (error 28.05%). (Hien.Nguyen, 2007) included only the adjustment factor of vehicle type. (Minh.C.C, 2003) was based on the multi-linear regression modelm, which has been applied in this study. (Tho.P.C, 2003) did not consider the impact of vehicle types and other factors. To sum up, the proposed model seems to be much improved as compared to the previously developed models.

7. CONCLUSION

This study has brought the new understandings of the mixed traffic flows at signalized intersections. The main contributions of this study include proposing the effective green time computation method and building the saturation flow rate formula in motorcycle dominant cities, taking into account of approach width, vehicle type, right turns of passenger car, and duration of green time. The developed model can be used for designing signal control method and signalized intersection organization. Due to limitation of data and time, other influential factors have not been investigated, such as approach gradient, weather, parking, and pedestrian crossing. It is noted that the left-turn vehicles of the opposite direction may have a higher effect on the saturation flow rate than the right-turn four-wheeled vehicles of the same direction. Further, the effective green time may need to be calculated based on a new method to reflect the unique characteristics of the traffic volume changes over green time. These issues remain a task in the future study to further improve the developed models.

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