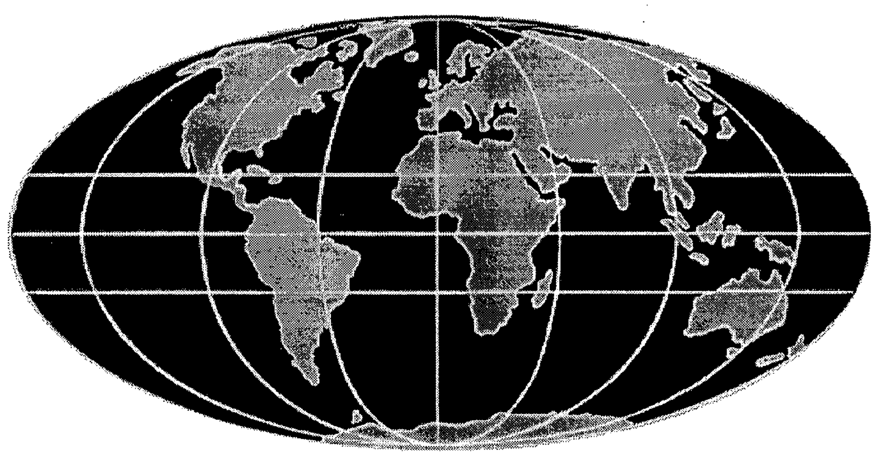
TRANSPORT RESEARCH LABORATORY

DFID Department For International Development

TITLE: Simplified saturation flow data collection methods

by: J Turner and G Harahap



Overseas Centre
Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

PA1292/93

Turner, J and G Harahap, 1993. Simplified saturation flow data collection methods.
In: **CODATU VI Conference on the Development and Planning of Urban Transport, Tunis, February 1993.**

Simplified saturation flow data collection methods

Jeff Turner
Overseas Unit
TRL
Crowthorne, Berks
United Kingdom

Ghandi Harahap
IRE
Bandung, Indonesia

SUMMARY:

Accurate saturation flow values are a fundamental building block in the management of efficient urban traffic signal control and junction design. This paper describes an evaluation of several alternate methods to collect accurate saturation flow data in 'typical' developing country conditions.

Three methods were tested side-by-side at 4 junctions, with 57 cases being surveyed, each of 100 consecutive cycles. The observed data reported a mean saturation flow of 2890 passenger car units per hour of green. Statistical testing showed that the different methods were as accurate as each other, with no one method consistently finding different results from the other two.

This paper further describes how the data could be used for further saturation flow analysis. A range of site-specific PCU values were obtained using *synchronous* multiple linear regression. Predictive saturation flow models were then derived using multiple regression techniques.

SOMMAIRE:

La précision des valeurs de circulation de saturation représente un élément fondamental de la gestion d'une conception efficace des embranchements et de la régulation des signaux pour la circulation urbaine. Ce rapport décrit l'évaluation de plusieurs méthodes différentes de collecte des données exactes sur la circulation de saturation dans les conditions 'typiques' d'un pays en cours de développement.

Trois méthodes ont été essayées côte à côte à 4 embranchements, 57 cas étant examinés, de 100 cycles consécutifs chacun. Les données observées ont indiqué une circulation de saturation moyenne de 2890 voitures particulières par heure de signal au vert. Les vérifications statistiques effectuées ont montré que les différentes méthodes étaient aussi précises les unes que les autres, aucune méthode individuelle ne produisant régulièrement des résultats différents de ceux des deux autres.

Ce rapport décrit de plus comment les données pourraient être utilisées pour une analyse complémentaire de la circulation de saturation. En utilisant la régression linéaire multiple *synchrone*, on a obtenu une gamme de valeurs en termes de voitures particulières spécifiques aux sites considérés. Il a été alors dérivé des modèles prédictifs de circulation de saturation par application des techniques de la régression multiple.

Simplified saturation flow data collection methods

Jeff Turner
Overseas Unit
TRL
Crowthorne, Berks
United Kingdom

Ghandi Harahap
IRE
Bandung, Indonesia

1. INTRODUCTION

Saturation flow is a very important road traffic performance measure of the maximum rate of flow; it is used extensively in junction design and control applications. The data collection techniques used to determine this performance measure have been developed in the industrialised world. However, traffic conditions in the developing world are often somewhat different. The difference arises from the influence of the following factors:-

Vehicle mix
a multitude of different types of vehicles, both motorised and non-motorised, with different operating performances
Driver behaviour
poor lane discipline and observance of traffic rules
Public transport
varied mix of bus types, stopping places and driving styles
Roadside activity
roadside land-uses generate parking and non-transport activities which reduce effective road width

As a result, data collection methods may not be able to cope with the wide range of vehicle types or 'uncontrolled' activity that characterises traffic behaviour in developing countries. Furthermore, many of the standard techniques rely on sophisticated dataloggers or traffic counters which may be too expensive for use in developing countries.

In order to develop an acceptable method for saturation flow measurement, a study was undertaken, in Bandung, Indonesia, with the following objectives:

- to test several alternate methods of collecting saturation flow data, for ease of use in the prevailing traffic conditions

- to assess how well each method determines saturation flow estimates.

This paper reviews the concept of saturation flow and the standard methods by which it is measured. The study undertaken in Bandung is described and the results of the comparative performance of different methods discussed. The opportunity was also taken to use the data to show how to derive PCU values and predictive saturation flow models.

2. SATURATION FLOW

2.1. Concept

Saturation flow is a macro performance measure of junction operation. It is an indication of the potential capacity of a junction when operating under 'ideal' conditions.

An idealised view of saturation flow at a signalised junction is illustrated in Figure 1. As the traffic signal aspect shows green , there is first a very short gap as the first driver reacts to the change. The rate of vehicles crossing the stopline then rises at an increasing rate, as vehicles accelerate to the speed determined by the cars they are following. Vehicles soon reach a state where they are following one another across the stopline at a constant gap or headway. This constant rate is represented by the plateau of this flow profile. In a saturated junction, the queue formed when the lights were at red will be too long to clear in the green period and so cars will be following each other at constant spacing during the green period. The flow rate will only drop as the lights show an amber aspect. Here the rate will decrease at an increasing rate as initially vehicles carry on through the stopline on amber and then stop as the signals show red. The saturation flow is calculated by making the curved profile into a rectangle from which the dimensions can be measured. This is achieved by introducing the idea of **lost time** and **effective green time**. The lost time is the time from the start of green to a point where vehicles are flowing at half the maximum flow **plus** the time from where vehicles are flowing at half the maximum flow at the end of saturation to the beginning of the red period.

In order to compare flows from different sites with different traffic composition, saturation flows are expressed not in vehicles but in generic units called Passenger Car Units (PCU). These units are an indicator of the space different vehicle types occupy, expressed relative to that of a passenger car.

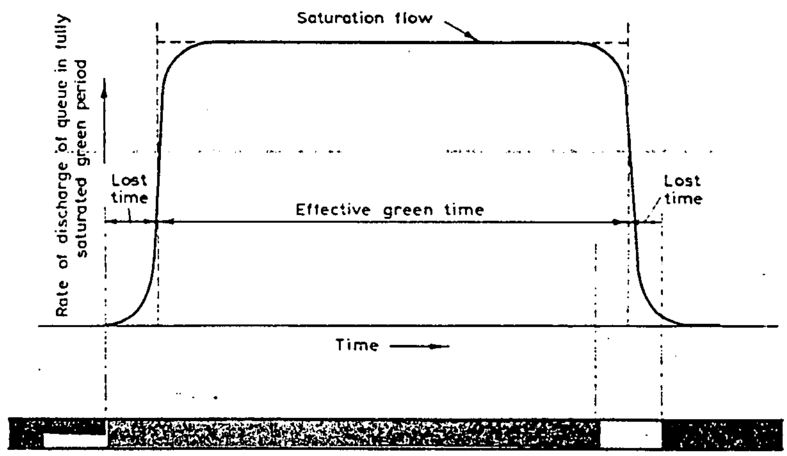


Fig 1. The flow of traffic during the green period from a saturated approach

2.2. Survey and analysis methods

Several survey methods of collecting saturation flow data have been developed over the years. Amongst the most notable of these is the Webster method. This requires one surveyor to carry out a classified count of vehicles crossing the stopline in 6-second periods from the beginning of green until the last vehicle has crossed the stopline - even if the signals display amber or red (see Figure 1).

Most studies obtain average saturation flow values from calculating the saturation flow for each observed cycle using pre-determined PCU values and averaging across a representative sample. Results from both western and developing world studies can be seen in table 1. It must be noted that most of the western findings stem from nationwide public road surveys whereas those from the less developing countries are often based on a much smaller, spatially concentrated sample.

The western studies have a range of saturation flow values of somewhere between 1700 and 2080 PCU/hr green time. This is for straight-ahead traffic in a 3.5 metre wide lane at level gradient, without opposed flow. Studies derived in developing countries have a value of between 1200 and 2000 for the same conditions. Variations in saturation flow measurements are likely to be influenced by the geometric characteristics of the junction, as well as extraneous factors like the level of pedestrian activity.

Study	Country	Mean (PCU/HR)	Sample size
Webster & Cobbe	UK	1800	100
Kimber *et al.*	UK	2080	64
Miller	Australia	1710	-
Branston	UK	1778	5
H.E.L Athens	Greece	1972	35
Shoukry & Huzayyin	Egypt	1617	18
Hussain	Malaysia	1945	50
Coeymans & Meely	Chile	1603	4
Bhattacharya & Bhattacharya	India	1232	20
De Andrade	Brazil	1660	125

Table 1. Previous studies' saturation flow values

3. THE TRIAL STUDY OF SATURATION FLOW MEASUREMENT

3.1. Outline

This trial was conducted in Bandung, Indonesia, a medium-sized city in West Java of some 2 million inhabitants. Traffic composition in the country as a whole is roughly 35-50 percent motorcycles, 40-50 percent motor vehicles and the remainder a multitude of animal and human-powered modes. Traffic behaviour is characterised by a lack of lane discipline and queuing behaviour that does not necessarily follow the first-come, first-served principle (Sutomo, 1992). Surveys were undertaken by Overseas Unit, TRL, in collaboration with the Institute of Road Engineering, Urban Traffic Division, during the period November 1989-November 1990. A pilot study was undertaken to gain some appreciation of the problems of measurement and to help determine what methods should be tested fully. The main criteria used for establishing which methods to test more intensively was ease of implementation.

3.2. Pilot study

The Webster method was tried out. It was found that the need to timekeep and record the number of vehicles was proving very difficult in the undisciplined flow situation common to Bandung. To make things easier the time period was changed to 5 seconds from 6 seconds, a more obvious time division on a modern digital stopwatch. The job of noting the time when to change recording time periods was also given to a separate observer. This observer could also shout out the vehicle classification as it passed to account for fluctuations in vehicle mix; leaving the original observer to record each vehicle as it passed, its class and which time period it passed in. This adapted procedure will be referred to as **Method 1**.

An alternative method piloted recorded saturated vehicle departures and their class from after a certain time lag until the departure of the last vehicle in the queue. Here again two observers were used, one to monitor the time and shout out the passing vehicle classification, the other to record it all manually. Two separate methods were used; one where the start period was 10 seconds long (**Method 2**) and one where the start period was equal to the time for 3 vehicles to depart (**Method 3**).

3.3. Main survey

In the main survey these separate methods were used at the arms of four junctions with a total of 57 cases surveyed. Each case was surveyed for 100 consecutive cycles, during the morning peak period. In some cases the surveys were made across the full-width of the arm and in other cases lane-by-lane. The average width of lanes surveyed was 3.36 metres. Where the whole approach stopline was surveyed the average width was 7.21 metres.

3.4. Preliminary analysis

The value of saturation flow was calculated from the observations taken using, initially, PCU values adapted from standard western values for the vehicle classes used. The assumed values used were:-

Vehicle Type	M/cycle	Minibus	Bus	Light Truck	Tractor/Trailer
PCU	0.5	1.5	2.5	2.0	3.0

Table 2. PCU values used in preliminary analysis

For each 100 cycle survey the distribution of calculated saturation flows was plotted. Summary statistics (mean, standard deviation, variance, range and standard error) for each 100 cycle survey were produced. Some of the results for the whole study and results disaggregated by collection method are shown below.

Saturation Flow by:	Mean	Std Deviation.	Variance
Overall Average	2890	1150	1.5+E6
Method 1	2914	1036	1.4+E6
Method 2	2674	1563	2.3+E6
Method 3	3068	886	946767
Lane-by-lane	1922	1049	1.2+E6
Full-width	4049	1269	2.0+E6

Table 3. Statistics for observed data by collection method and whether traffic observed in lanes or across whole approach

All three methods report what appear to be similar results. There is, however, a noticeable difference between the mean for the data collected on a lane-by-lane basis and that collected across the full-width of the approach stopline, with the latter reporting a higher average figure. This is expected as, on average, the width of road surveyed when using the full-width of the stopline is greater than for a lane-by-lane method, which would, in turn, suggest a higher saturation flow.

Further comparative assessment of the collected data was then conducted. One method of this was to produce scatter plots of one method's observations against that of another. An example of is shown in Fig. 2. Inspection of these plots suggest no strong bias towards any one method.

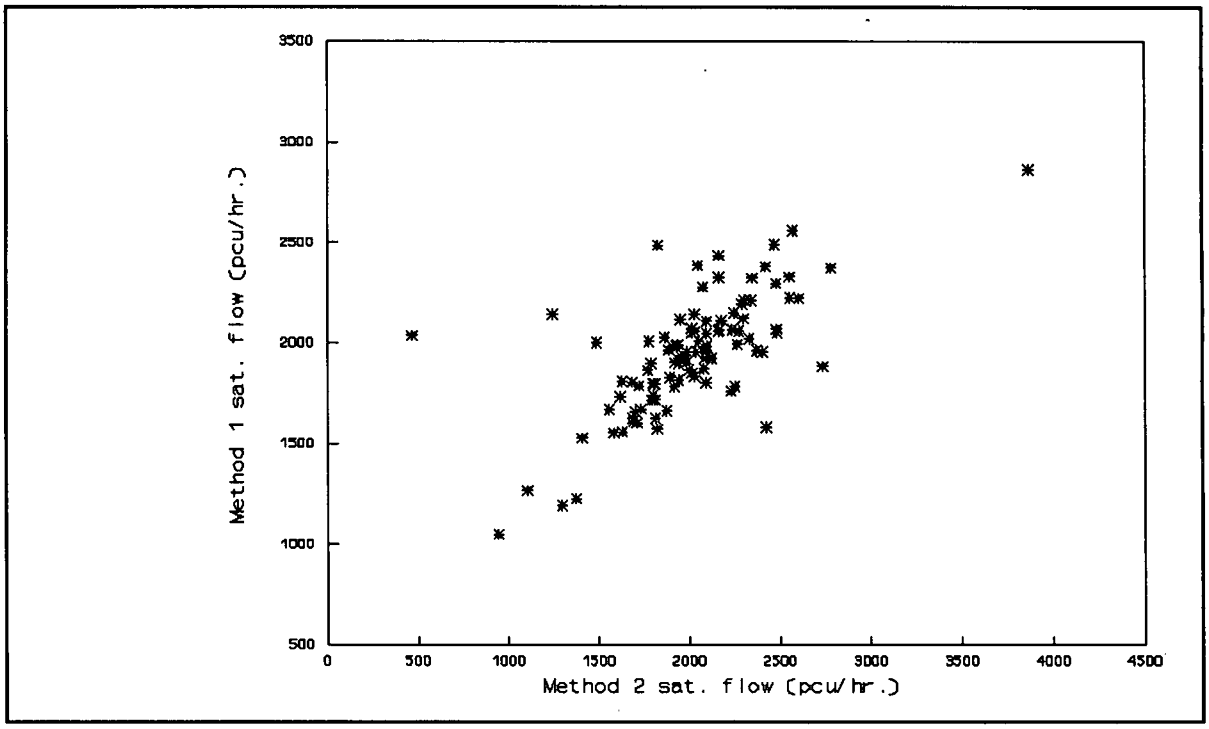


Fig 2. Saturation flow data collected method 1 against data collected by method 2.

Variation between cycles and between methods can be indicated by the sampling error. As each survey was carried out for only one day at each site, there was no information on day-to-day variation. As the sample size per survey for each method was a 100 cycles, the sampling error was found to be 4 per cent. Comparative statistical testing indicated that all methods do not consistently report different results and the use of any of these three methods is as reliable a measurement technique as each other.

4. PCU ANALYSIS

The three different data collection methods had now been assessed for their practical ease-of-use and statistical performance. Whilst it is very important to be able to derive site-specific saturation flow values for the purposes of signal-setting, these cannot be accurately derived without accurate locally-determined PCU values. This section looks at how useful the methods, tried in this study, are in deriving PCU values.

In synchronous regression, the number, X_i, of vehicle departures of each vehicle class i are recorded over a time period T, beginning and ending with the departure of a vehicle (Fig 3). Time period T is regressed on X_i to obtain estimates of the coefficients of the equation, thus:-

$$T = Constant + \eta_1 X_1 + \dots \eta_n X_n$$

The PCU values are obtained from the ratio of the constants of the vehicle type n, with that of the constant for cars, and saturation flow is the reciprocal of the coefficient for cars.

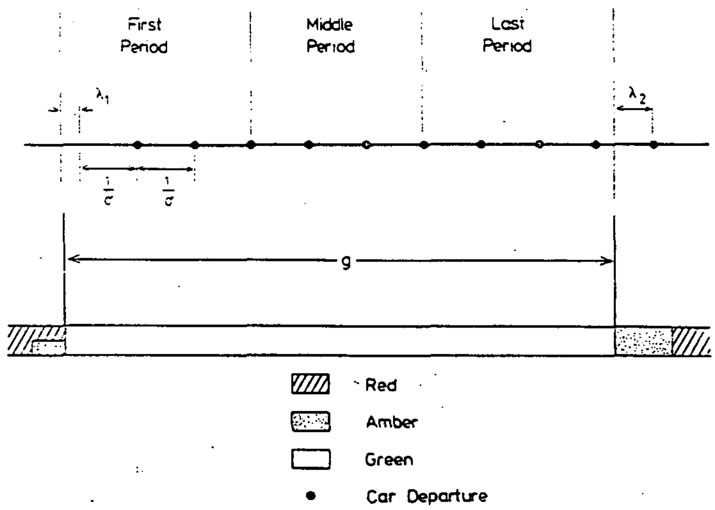


Fig. 3. Definitions of the counting periods for synchronous counting methods (Branston and van Zuylen, 1978)

The PCU values of each vehicle class are the coefficients and the saturation flow is the coefficient of the term T.

Data from the method identified as being compatible with *synchronous* regression was used as input to a multiple regression model of the form shown above. The variables used correspond to those used in the data collection and time T was taken as the difference between the first and last time recorded. Multiple stepwise regressions were performed and the coefficients of the significant independent variables were noted. The PCU values for each class were derived from the ratios of these coefficients to that of the passenger car. This analysis was performed for every survey carried out using the method with a 3-vehicle start lag. The overall results were as follows:-

Vehicle Type	M/cycle	Car	Minibus	Bus	Light Truck
PCU	0.37	1.0	2.18	2.23	1.65

Table 4. The PCU values derived from synchronous regression analysis

Minibuses were shown to have a bigger influence, in terms of space required, than light trucks. This could be as a result of their behaviour in stopping at or near junctions to ply trade.

5. PREDICTIVE SATURATION FLOW MODELS

The average PCU values calculated were used to recalculate the saturation flow values for each survey, replacing the assumed western values with the site-specific values. Regression analysis was used to examine the impact of various independent factors on the variation in flow monitored at each site. The independent variables used are listed in Table 5. Selection of these variables was largely on the basis of ease of collection and the experience of earlier studies.

Variable	Variable Name	Description
A	SITE NO.	No. of junction from MAAP network.
B	ARM	Arm of junction being surveyed. Noted as A-D counted clockwise from the North
C	METHOD	Survey method used; 1=time slicemethod; 2=10 second method; 3=3-car method.
D	LANE	Surveyed lane counted from 1 on the nearside.
E	TYPE	Either surveyed lane-by-lane or across the full approach.
F	SAT FLOW.	Observed Saturation Flow.
H	VAR.	Variance of observed saturation flow across each 100 cycle survey.
I	WIDTH	Width of lane or approach at stopline being surveyed.
J	MCPCU	PCU value assigned to motorcycles when calculating observed saturation flow.
K	SIGSET	Length of signal green time for approach being surveyed.
L	M/C COMP	Percentage of total flow made up by motorcycles.
M	L/TURN W	Width of junction exit for left-turning traffic.
N	R/TURN W	Width of junction exit for right-turning traffic.
O	STR-ON W	Width of junction exit for traffic travelling straight-on.
Q	M/B COMP	Percentage of total flow made up by minibuses.
R	B COMP	Percentage of total flow made up of buses.
S	T COMP	Percentage of total flow made up by trucks.

Table 4. Regression variables.

A dataset was created by combining the average saturation flow for each collection method for a site of 100 cycles with the data on each of the variables for that site. This was created for all 57 cases surveyed. This dataset was then regressed, with saturation flow as the dependent variable. The significant variables and the degree to which they add to the explanation of data variation are detailed below. The standard error for each variable is also given. As an additional check, the databases were combined for a separate run of the regression package to test whether there was any significant difference between the data collected on a lane basis and that which had been collected across the whole approach width. A dummy variable was added to show on what basis the data had been collected in each case. The results suggest that there is no significant difference between the collection procedures, as the dummy variable was not significant. It was thus reasonable to combine datasets for further analysis.

Some of the most statistically significant models are shown in Table 6.

Simple models (width only)	
1. $S = 524.6w$	(forced through origin)
	$R^2 = 0.92$
2. $S = 964 + 349w$	$R^2 = 0.66$
Multi-variate models	
3. $S = 1035 + 425w - 110_{tcomp} + 32_{stw} - 11_{m/c\ comp} + 47_{b\ comp}$	(by-lane)
	$R^2 = 0.49$
4. $S = 318_{sigset} + 173w + 67_{stw} - 4667$	(full-width) $R^2 = 0.97$

Table 6. Predictive saturation flow models derived the regression analysis

The simplest model is biased as it is forced through the origin, though it was included to allow comparison with the Webster model (Webster and Cobbe, 1966). It seems to provide a very close resemblance to that model, although to what extent this is due to the inherent bias is unclear. Perhaps a better indication can be given by the model derived with an intercept term. Whilst reporting a reduced degree of explanation for its width variable compared to the model without an intercept, Equation 2 does bear a resemblance to Western-derived models of Miller and Branston.

The degree to which Equation 2 compares with other studies can also be seen in Fig. 4. All the models predict lower estimates of saturation flow, as a function of the approach width, than this study's model, at approach widths less than 5.8 metres. This may suggest that the failure to record turning proportions may be leading to a model that assumes the approaches to be operating more efficiently than they actually are.

The dataset was disaggregated on the basis of data collected from across the whole stopline and that collected from individual lanes. This was to see if a step function like that reported by Kimber *et al.* (1985) could be used to predict the saturation flow. Equation 3 was the resulting predictive model for data collected on an individual lane basis. This was derived from data collected from lanes of between 2.6 and 4.7 metres width. The degree of explanation is low and each one of the terms adds an equal amount to the explanatory value of this model.

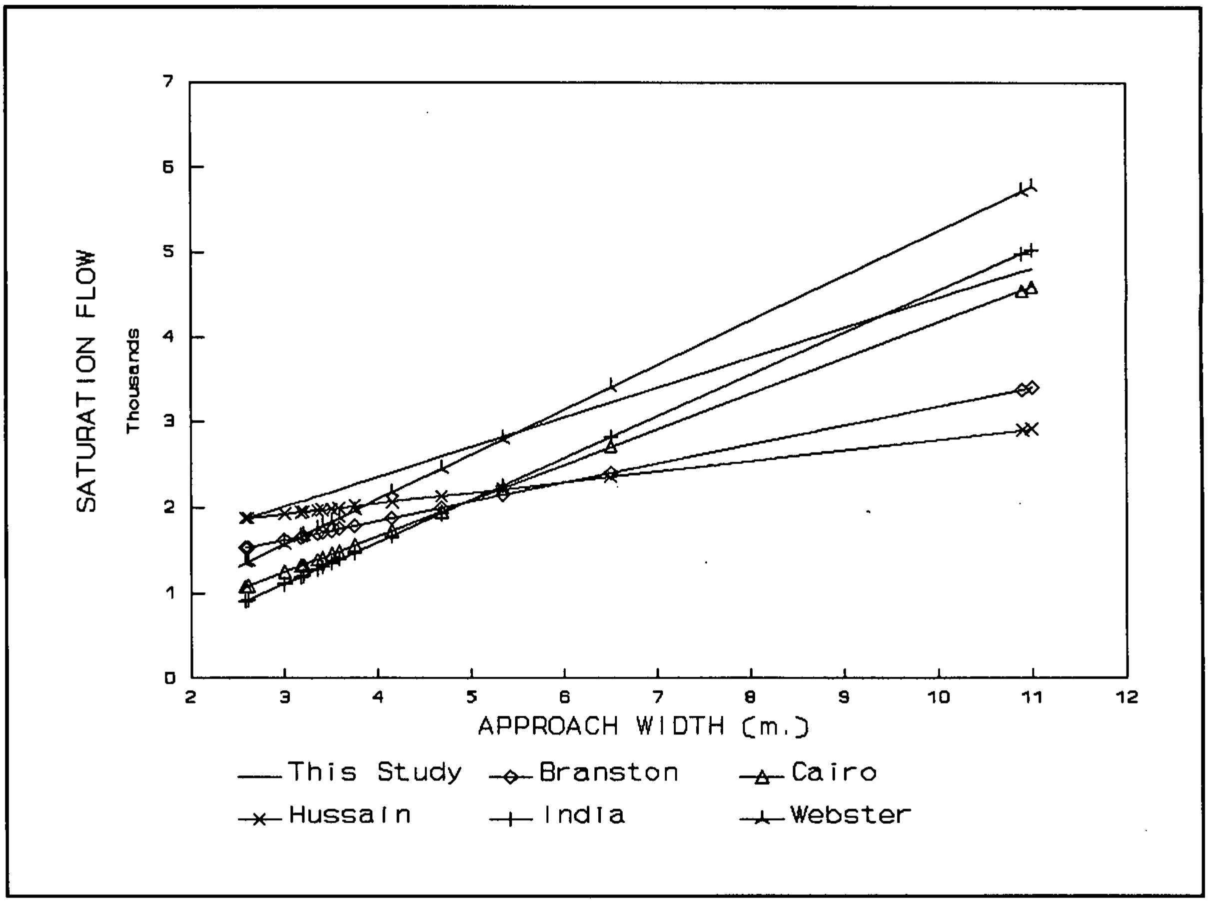


Fig. 4. Comparative model results: Saturation flow against approach Width.

Equation 4 predicts saturation flow on the basis of data collected from vehicle departures across the whole of the stopline. A much higher degree of explanation is achieved with the length of green time accounting for 86 per cent of the variation. This may be as a result of wider stoplines that operate with a varying number of lanes in use as the green period goes on. At the start of green, there may be parallel queues for left, straight-on and right-turning traffic, with large numbers of motorcycles grouped at the stopline. As the green phase progresses, these may reduce into one stream, increasingly composed of just light vehicles. Similar evidence for the effect of length of green time in Bandung, was also found by Bång (1992).

6. CONCLUSIONS

Accurate saturation flow values are a fundamental building block in the management of efficient urban traffic signal control and junction design. This study has attempted to evaluate several alternate methods to collect accurate saturation flow data in 'typical' developing country conditions.

All three methods tested concentrated on measuring the period of traffic flow from when the start lag had elapsed to when the last vehicle, queuing at the beginning of the green phase, had departed. The methods were tested side-by-side at 4 junctions, with 57 cases being surveyed, each of 100 consecutive cycles.

The observed data reported a mean saturation flow of 2890 passenger car units per hour of green. Statistical testing showed that the different methods were as accurate as each other, with no one method consistently finding different results from the other two.

The evaluation was further extended to examine how the data could be used for further saturation flow analysis. A range of site-specific PCU values were obtained using *synchronous* multiple linear regression. The average saturation flow for each survey was recalculated using these values and multiple linear regression techniques were then used to derive predictive saturation flow models. The saturation flow values, both all together and disaggregated by lanes or full approach collection criteria, were regressed against several junction characteristics. The resulting models and statistical performance indicators were reported.

The three methods evaluated in this study appear to offer relatively accurate ways of measuring saturation flow on-site, which require a minimum of technical competence and equipment. For ease of use our surveyors found method 2, where counting begins 10-second after the beginning of the green period, the most appropriate.

The values found from surveys using any of these methods, can be input directly into any signal-setting equation to allow the easy determination of up-to-date optimum signal timings, as part of the traffic engineers efforts of maximising network capacity and minimising congestion.

7. REFERENCES

BANG, K. (1992). Indonesian Highway Capacity Manual, Summary Report, Bina Marga, (unpublished).

BHATTACHARYA, P G and BHATTACHARYA, A K (1982). Observation and Analysis of Saturation Flow through Signalised Intersections in Calcutta. *Indian Highways* April 1982 pp 11-33.

BRANSTON, D (1979). Some factors affecting the capacity of signalised intersections. *Traffic Engineering and Control 20 (8/9)*, pp 390-396.

BRANSTON, D and VAN ZUYLEN, H (1978). The Estimation of Saturation Flow, Effective Green Time and Passenger Car Equivalents at Traffic Signals by Multiple Regression Techniques. *Transportation Research 12(1)*, pp 47-53.

COEYMANS, J E and MEELY, C B (?). Basic Traffic Parameters in the case of Santiago. *(Unpublished)*.

DE ANDRADE, J P (1988). The Performance of Urban Intersections in Brazil. Transportation Research Group, Department of Civil Engineering, University of Southampton, Doctoral Thesis (Unpublished).

HIGHWAY ENGINEERING LABORATORY (H.E.L), (1990). Improvements to Advanced Modelling Techniques for Traffic Engineering Applications in the European Community. Report 1. National Technical University of Athens.

HUSSAIN, A M (1990). Determination of Saturation Flows at Signalised Intersections in Malaysian Urban Areas. 6th REAAA Conference Proceedings Volume 2.

HUZAYYIN, A S and SHOUKRY, W S (1986). Saturation Flow and Effective Approach Width at Signalised Intersections in Greater Cairo. 6th African Highway IRF Conference.

KIMBER, R M; McDONALD, M and HOUNSELL, N (1985). Passenger Car Units in Saturation Flow: Concept, Definition, Derivation. *Transportation Research B (19B),* pp 39-61.

KIMBER, R M; McDONALD, M and HOUNSELL, N (1986). The Prediction of Saturation Flows for Road Junctions Controlled by Traffic Signals. *Research Report 67.* Transport and Road Research Laboratory, Crowthorne.

MILLER, A J (1968). The Capacity of Signalised Intersections in Australia. ARRB Bulletin 3, Australian Road Research Board.

ROAD RESEARCH LABORATORY (1963). A Method for Measuring Saturation Flow at Traffic Signals. Road Reasearch Laboratory, Harmondsworth.

SUTOMO, H (1992). Modelling mixed traffic in a signalised junction. Phd. Thesis, University of Leeds, Institute of Transport Studies (unpublished).

WEBSTER, F V and COBBE, B M (1966). Traffic Signals. Technical Paper 56. HMSO, London.

8. ACKNOWLEDGEMENTS

This work forms part of the programme of the Urban Transport and Traffic Management section of the Overseas Unit (Unit Head: J S Yerrell) of the Transport Research Laboratory and is published by permission of the Chief Executive.