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Recalibrating SIDRA's Saturation Flow Estimation Models

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ABSTRACT

Most analysis procedures recommend the use of measured saturation flows rather than estimates because they are notoriously erratic and are dependent on a multitude of local conditions. However, it is often impractical to measure prevailing saturation flow rates so it is necessary to develop estimates of saturation flow that are based on readily available geometric, environmental and traffic characteristics. This paper outlines the principal results of a major research project into saturation flows at signalised intersections in Melbourne. The models used by SIDRA (Signalised Intersection Design and Research Aid) for saturation flow estimation are recalibrated for a recently collected data set. The new models enable enhanced saturation flow estimation for a range of traffic, geometric and environmental conditions. The models can be adopted easily in SIDRA by editing a default values file and are, therefore, of immediate use to traffic engineers and planners.

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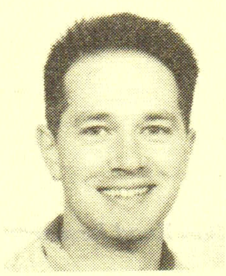

Andrew Cuddon graduated from the University of Melbourne in 1986 with an Honours degree in Civil Engineering. He became involved in transport engineering through part-time work with TTM Consulting Pty Ltd. Andrew's interest in traffic engineering led to Masters and Ph.D. degrees, both of which involved research into saturation flows at signalised intersections. He has lived in London where he was employed as a Senior Traffic Engineer by JMP Consultants Ltd. In that role he worked on research projects for TRRL and the traffic modelling and planning for the London Docklands re-development. Andrew is currently employed as a research fellow by The Transport Research Centre at The University of Melbourne. He is working primarily on the Victorian Activities and Travel Survey (VATS) and related projects.

1. INTRODUCTION

Procedures for signalised intersection analysis often recommend the use of measured saturation flows because they are notoriously erratic and are very much dependent on local conditions. However, it is often impractical to measure prevailing saturation flow rates for an existing site and they are impossible to measure for a signal installation that is yet to be constructed. In these situations it is necessary to develop estimates of saturation flow that are based on readily available geometric, environmental and traffic characteristics.

SIDRA (Signalised Intersection Design and Research Aid: Akçelik and Besley 1991) is the most common tool used for intersection analysis in Australia. In recent years SIDRA's analysis techniques have undergone many enhancements but, until recently, the fundamental input data (the saturation flows) had not been updated.

A recent study by Monash University of lane saturation flows at signalised intersections in Melbourne (Cuddon 1993a) now enables SIDRA to utilise updated saturation flow models. The newly developed saturation flow models are outlined in this paper.

2. DATA COLLECTION

Headway data for each vehicle crossing the stop line were collected via the SATFLOW software (Cuddon 1993b) that was developed for this project. Data were recorded by pressing a key on the laptop computer keyboard each time the rear-most axle of a vehicle crossed the stop line. SATFLOW enabled vehicles to be classified and signal changes to be identified according to the key that was pressed. Data input was highly regulated so that invalid keystrokes were not accepted as legitimate data.

Over a period of 18 months data were collected for a total of 163 lanes at 71 sites throughout the Melbourne Metropolitan area. The resulting database comprised over 5000 green periods and resulted in more than 40,000 saturation headways.

3. MODEL FORM

The saturation flow models presented in this paper are in the format most commonly used for saturation flow estimation. These models involve a basic or ideal saturation flow, in through car units, which is factored up and down for conditions such as traffic composition, geometry and environment. The fundamental model for saturation flow estimation is:

$$S_{veh} = f_1 f_2 \cdots f_n S_b \qquad (1)$$

where:
- S_{veh} = adjusted saturation flow (veh/h);
- S_b = basic saturation flow (tcu/h); and
- f_i = saturation flow adjustment factors, i = 1 to n.

SIDRA estimates saturation flow by adjusting a basic saturation flow for factors relating to vehicle composition, lane width, approach grade, and bus and parking conditions. The basic saturation flow is the starting point for saturation flow estimation. /It is often selected from five environment class categories which relate to general environment and traffic characteristics. The first three are essentially the environment classes A, B, and C that are defined in ARR 123 (Akçelik 1981) as good, average, and poor conditions. Two additional environment classes are also provided for sites with very poor and very good conditions. The basic saturation flow for each environment class has essentially been derived from the surveys of the late 1960's (Miller 1968).

Conditions that influence all vehicles in a lane equally are allowed for by the saturation flow adjustment factors (eg. lane width, parking and bus factors). Conditions that relate to individual vehicle types (eg. turn radius, heavy vehicles) are specified in the through car equivalents which are then converted to a traffic composition factor.

4. DATA ANALYSIS

Saturation flow was derived from the average saturation headway with the first four vehicles in each green period discounted to allow for acceleration effects. The saturation headway data were averaged for each lane sample and then converted to a flow rate.

Basic saturation flows were calculated as the average saturation flow (in through car units) for through lanes in each environment class. However, to account for the relative accuracy for lane samples with varying numbers of saturation headways, each lane of data was weighted by the inverse of its saturation headway variance.

Sites with only minimal interference to traffic flow were selected for the study because only the most fundamental aspects of saturation flow were under investigation and significant interference to the traffic progression would have detracted from the analyses. Therefore, there were no sites with poor or very poor conditions so the basic saturation flows for environment classes 3 and 4 had to be extrapolated form the other values. Hence, they are only approximations.

Stepwise regression techniques were used to determine the adjustment factors that should be included in the models. Both linear and non-linear regression models were considered but only the non-linear factor models are discussed in this paper because they can be implemented in SIDRA without changing the software. In addition, a set of equations that explicitly modelled many factors that affect saturation flow rather than using an environment class were also developed (Cuddon 1993a) but the limited length of this paper does not allow a discussion of these models.

5. BASIC SATURATION FLOWS

The saturation flows, in vehicle units, were converted to through car units by the new heavy vehicle equivalent of 1.65 tcu/veh (See Section 6) before being grouped by environment class.

Table 1 shows that the new basic saturation flows are higher than those currently recommended for use in SIDRA. The increase in basic saturation flow is dependent on environment class; the better environment classes produced the greater increases. The increases appear small, but when compared to the amount of change produced by the usual adjustment factors, they are substantial. This is especially true for the better environment classes.

The increase in basic saturation flow may be attributed to improvements in vehicle performance and changes in driver behaviour caused by refinements in intersection design and lane layout practice. The effects of these alterations are more substantial at larger intersections where design standards have changed markedly since the late 1960's. At smaller intersections, space limitations have not enabled substantial improvements in intersection geometry so the increases in basic saturation flow are smaller.

TABLE 1

New basic saturation flows

Environment Class	General Conditions	SIDRA Basic Saturation Flow (tcu/h)	New Basic Saturation Flow (tcu/h)	Increase (%)
5	Very Good	2000	2150	7.5
1	Good	1850	1950	5.4
2	Average	1700	1775	4.4
3*	Poor	1580	1625	2.8
4*	Very Poor	1440	1460	1.4

* Values for environment classes 3 and 4 were extrapolated from the other values.

6. THROUGH CAR EQUIVALENTS

Composition of the traffic stream is allowed for via a traffic composition factor that weights the through car equivalent (passenger car equivalent) for each vehicle and turn type by its proportion in the traffic stream (See *Equation 2*).

$$f_c = 1 / \sum_{i=1}^{i=n} \rho_i e_i \tag{2}$$

where:
- f_c = traffic composition factor;
- e_i = through car equivalent for vehicle/turn type i (tcu/veh)
- ρ_i = proportion of vehicles of type/turn i in the traffic stream; and
- n = number of vehicle/turn categories in the traffic stream.

Table 2 shows the new through car equivalents for a four-way ('detailed') vehicle classification system. The standard heavy vehicle category that is used by SIDRA combines the light commercial, rigid truck and articulated truck categories.

TABLE 2

Through car equivalents for the detailed vehicle classification system

	Through lanes	Left turn lanes	Right turn lanes
Car	1.00	1.38	1.16
Light commercial	1.26	2.11	1.49
Rigid truck	1.77	2.48	2.11
Articulated Truck	3.22	3.67	3.20

All values are through car units

There is significant variation in the through car equivalents that comprise the heavy vehicle category; the values for articulated trucks are more than double those for light commercials and 50% greater than those for rigid trucks. Hence, especially for locations with high truck volumes, it is important that the traffic composition factor uses the detailed through car equivalents.

However, it is not common to have detailed traffic composition data for design purposes. Therefore, a classification system that discriminates only between cars and heavy vehicles is commonly used in SIDRA. The recommended through car equivalents for this aggregate classification system are compared with the existing SIDRA values in *Table 3*.

TABLE 3

Through car equivalents for the aggregate classification system

	Through lanes		Left Turn Lanes		Right Turn lanes	
	SIDRA	New value	SIDRA	New value	SIDRA	New value
Car	1.00	1.00	1.3	1.38	1.00	1.16
Heavy Vehicle	2.00	1.65	2.6	2.48	2.00	1.99

Notes:
1. All values are through car units
2. This table treats the left turns as *restricted* and the right turns as *normal.*
   Source: Akçelik (1990)

The proposed through car equivalent for through heavy vehicles is significantly lower than the value of 2.00 that is often assumed. However, it is closer to the value of 1.85 tcu/veh that Miller (1968) calculated (but for simplicity he recommended a value of 2 tcu/veh). An in-depth discussion of the new through car equivalents is provided in Cuddon and Ogden (1992).

7. LANE WIDTH FACTOR

Figure 1 shows a plot of the new and existing lane width adjustment factors. The existing SIDRA factor is valid for both through and turn lanes but the new factor is valid for through lanes only; lane width was not significant for turn lanes.

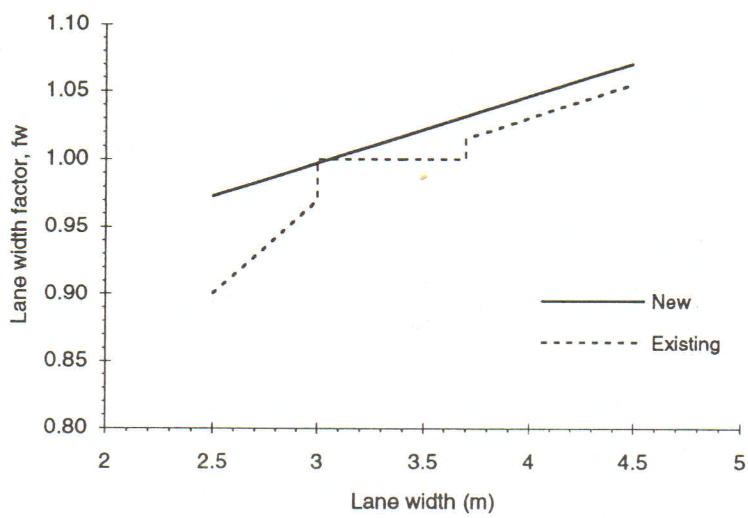

Fig. 1 - Lane width factors for through lanes

Above lane widths of 3.0 m the new and existing SIDRA factors are similar but for the smaller lane widths (below 3.0 m) the new factor reduces saturation flow much less than the existing SIDRA model. This suggests that small lane widths have less influence on saturation flow than in the late 1960's when the previous data were collected. The change in lane width effect may be due to improvements in intersection layout and lane marking, vehicle performance, and perhaps a reduction in passenger car size.

The new form of the lane width factor is shown in *Equation 3* below. The coefficient for turn lanes is not equal to unity. Hence, the basic saturation flows, which are common to all lane types, are under-estimated by about 10% for turn lanes.

$$f_w = \begin{cases} 0.85 + 0.05w & \text{for through lanes} \\ 1.10 & \text{for turn lanes} \end{cases} \quad (3)$$

where: f_w = lane width factor; and
w = lane width (m).

8. APPROACH GRADE FACTOR

Figure 2 shows a plot of the new and existing approach grade factors. Note that for the new factor the slope of the line for uphill grades is not significantly different from zero so a horizontal line would suffice.

The simple linear approach grade factor that is currently used by SIDRA was not significant for the new data. It appeared that a better approach grade factor may involve no adjustment for downhill grades and a simple linear function for uphill grades. This factor was substantially better than the existing model but for all lane types was still not statistically significant. Hence, the new approach grade factor is equal to unity for all lane types.

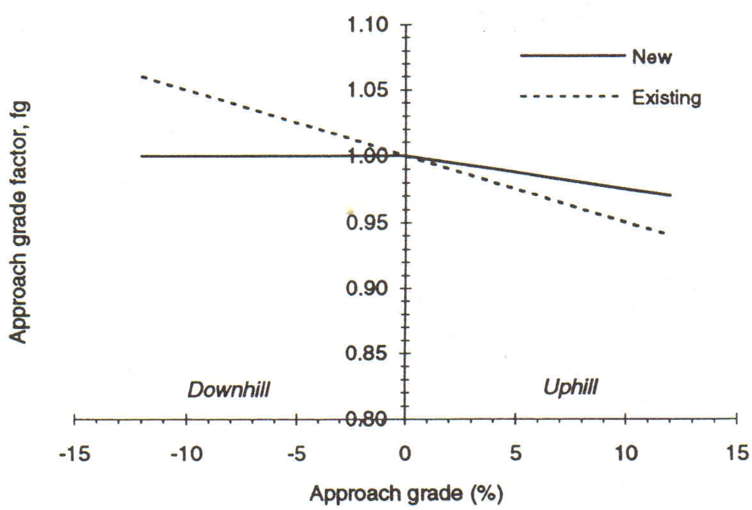

Fig. 2 - Approach grade factors for through lanes

9. GOODNESS OF FIT COMPARISON

Figure 3 shows a plot of the saturation flows estimated by the current SIDRA model against the observed values for through lanes. Almost all data points are below the 45° line so SIDRA consistently under-estimates the true saturation flows.

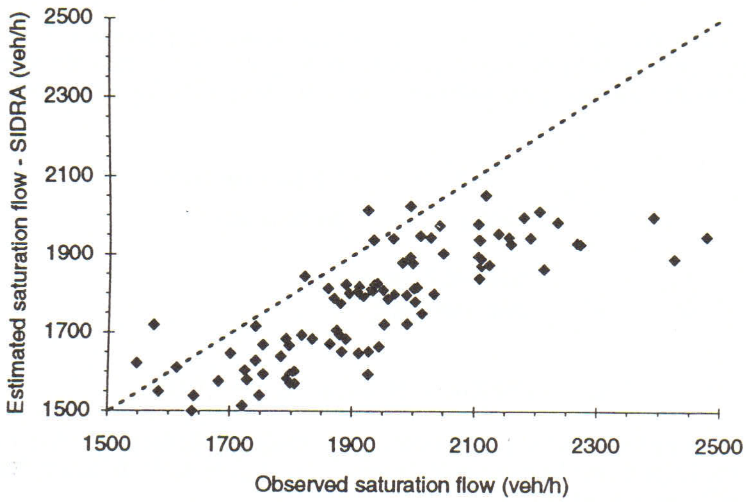

Fig. 3 - Existing model fit (through lanes)

Figure 4 shows a similar plot but the estimates were produced by the new model. The data points are now more evenly spread about the 45° line and the model's coefficient of determination (R^2) was 0.69 with a significance better than the 0.1% level. However, several outlying points remain. The outliers are at the high and the low end of the scale, suggesting that the model is adequate only for average conditions and may break down for extreme conditions.

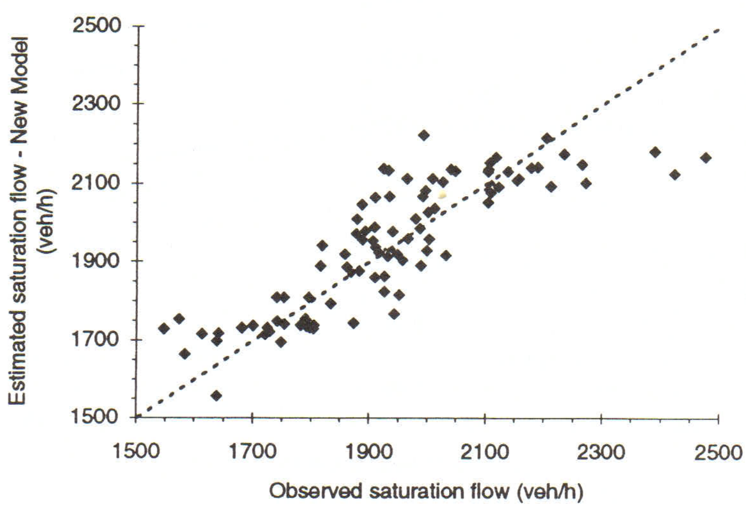

Fig. 4 - New model fit (through lanes)

The new model accounted for a substantially greater proportion of the data variation than the existing SIDRA model. Interestingly, although the existing SIDRA model consistently under-estimated saturation flow, the average error amounted to less than 10%. However, the maximum error for this model (22.0%) was much greater than that for the other models. The average and maximum errors for the new model were less than half those of the existing model. The turn lane models produced a poorer fit than the corresponding through lane models.

10. MODEL VALIDATION

The new saturation flow models were validated against 22 through lanes of data from the pilot survey (Cuddon and Bennett 1988) plus an additional data set of 11 turn lanes that were collected for validation purposes only. These data covered an adequate range of each parameter but lacked some of the extreme values that were exhibited by the calibration data.

Except for the existing SIDRA model, the errors were a few percent higher for the validation data than the calibration data. As the errors were small (<10%), all the new models accurately predicted saturation flow for a wide range of conditions.

11. ENHANCING THE MODELS

An attempt was made to enhance the new models by including additional factors to account for the traffic, geometric and environmental conditions that are not explicitly modelled. Unfortunately, due to the nature of the models and the data, the regression coefficients for any introduced factor were highly correlated with the existing coefficients. This high coefficient intercorrelation resulted in large coefficient standard errors and poor parameter estimates.

There were two possible explanations for this inability to extend the models. First, the basic saturation flows probably already contained much of the information that was being added to the models. Secondly, the format of the models meant that there was always some correlation between the regression coefficients and this became more evident when new factors were added to the model.

The analyses have shown that the bulk of the data variation is modelled by the basic saturation flows and only minor variation occurs from the adjustment factors. Therefore, for accurate saturation flow estimation, correct environment class selection is most important.

The most difficult aspect of saturation flow estimation in SIDRA is selecting an appropriate environment class or basic saturation flow for each lane of traffic. This process is very subjective and the only guidelines provided by SIDRA are the abstract definitions: good, average, poor, very poor, and very good. The basic saturation flows vary markedly between environment class so it is important that the appropriate class is selected for each lane. An incorrect decision may result in severely inaccurate saturation flows. Cuddon (1993a) examines additional models that enable saturation flow estimation without the hassle of environment class or basic saturation flow selection. In these models, factors that effect saturation flow are modelled explicitly.

12. EFFECT ON INTERSECTION CAPACITY

The new saturation flow models can be easily applied in SIDRA by editing the default values file. In this way the new saturation flow estimates were applied to three example intersections. The new saturation flows enabled a reduction in cycle time of between 8% - 10% and increased the intersection capacity by about 5%. These effects of course are very much dependent on the characteristics of the intersection and its traffic.

13. SUMMARY

The saturation flow estimation models that are currently in use by SIDRA have been recalibrated for updated saturation flow data. The new models enable enhanced saturation flow estimation for a range of traffic, geometric and environmental conditions. As the recalibrated models can be easily adopted in SIDRA by editing the default values file they are, therefore, of immediate use to practitioners.

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