Use of SCATS MF to Calibrate SIDRA Saturation Flow

David Nash, Rahmi Akçelik, Mark Besley and Ian Espada

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ABSTRACT

This document presents a discussion on the use of Maximum Flow values recorded in the SCATS traffic control system (SCATS MF) for calibrating Saturation Flow in SIDRA models of signalised intersections. While the concept of SCATS MF is similar to Saturation Flow, there are significant differences in how they are measured and applied. It is shown that valid values of SCATS MF are not available for many lanes, and where they are available, there are serious problems in translating SCATS MF to a reliable Saturation Flow value. Consequently, it is recommended that SCATS MF should not be used to calibrate SIDRA models. Instead, standard values of Basic Saturation Flow should be used, and models should be calibrated and validated against observed traffic performance measures.

1. Introduction

There is an emerging trend for SIDRA users to calibrate Saturation Flow in modelling existing signalised intersections to match the value of Maximum Flow measured and recorded in the SCATS traffic control system (SCATS MF). Saturation Flow and SCATS MF are quite similar in concept, but one cannot be substituted for the other due to significant differences in how these parameters are measured and applied.

This discussion paper explains the differences and recommends the best modelling practice.

Note that "right turn" in this paper applies to driving on the left-hand side of the road.

2. Saturation Flow for Modelling

Saturation Flow is the maximum achievable queue discharge flow rate across the stop line during the effective green period. It is the inverse of the saturation headway. As a simple example, a Saturation Flow of 1800 veh/h is equivalent to a saturation headway of 2 secs/veh.

When doing an analysis for a time period, usually 15 minutes to one hour, the Saturation Flow needs to be representative of the maximum flow rate that can be achieved in all cycles within that analysis period.

Saturation Flow is the key driver behaviour parameter used in signal timing, capacity and performance calculations for signalised intersections, interchanges and pedestrian crossings (Miller 1968a,b; Akçelik 1981; Hegarty and Pretty (1982); Cuddon and Ogden 1992; Cuddon 1993, 1994; Akçelik, Besley and Roper 1999; Akçelik and Besley 2002; TRB 2022).

It is important to recognise that the **Saturation Flow** used in SIDRA for signal timing and performance calculations is a value estimated by applying various adjustments to the **Basic Saturation Flow** as discussed in *Section 4* (the adjustments are given in SIDRA **Saturation Flows** output report). Basic Saturation Flow is the saturation flow rate achievable under ideal conditions at signals with no effects that reduce the steady queue discharge rate during the green period.

The SIDRA User Guide recommends calibration of Basic Saturation Flow in such a way that the Saturation Flow estimated by SIDRA under the operating conditions of the lane reflects the measured Saturation Flow. This enables the program to adjust the calibrated Basic Saturation Flow when the intersection geometry, demand volumes or other conditions are changed in various scenarios that are modelled. Therefore, it would not be appropriate if observed Saturation Flows are entered as input values directly.

3. How is SCATS MF Measured?

SCATS MF (Maximum Flow) is a key parameter used by the SCATS traffic control system in its operations (Lowrie 1982, 1990; Akçelik 1997; Akçelik, Besley and Chung 1998; Akçelik, Besley and Roper 1999; Akçelik and Besley 2002).

SCATS measures the flow rate for all strategic detectors every cycle. The highest flow rate in any cycle in the day is stored as the MF value after smoothing and provided it meets certain criteria. The eligibility criteria are set to ensure the values are in a reasonable range. If the eligibility criteria are not met in any of the cycles during the day, then an artificial value is calculated by SCATS and substituted as the MF value.

SCATS MF is smoothed over five days to ensure it does not vary too much from one day to the next.

The SCATS MF values are shown in the SCATS Strategic Input (SI) data. The meaning of the parameters is explained for this sample data:

SI196=4077,2!D#=3-4!
MF=1739#,+1572*!NF=0,0!
KP=103,98!AV=1657,2092!

- SI196 is the reference number of this SI data set,
- 4077 is the SCATS site number,
- The data is collected during signal group 2, or this could be specified as one or more phases,
- D# gives the detector numbers, 3-4,
- MF values relate to the listed detectors respectively,
- NF is a calibration factor for the Degree of Saturation calculation, usually left at 0,
- KP is the average occupancy per vehicle at maximum flow × 100 for the listed detectors, and
- AV is the average daily flow for the listed detectors.

The symbols next to the MF values are very important to understand:

means the MF has been manually entered and locked by a SCATS user,
* means the flow rates did not reach the eligibility conditions; an artificial estimate has been substituted by SCATS, and
+ means there is a Strategic Input (SI) alarm; the MF value is unreliable.

In a sample of three SCATS regions in Melbourne (Blackburn, Glen Iris and Carlton2), 38% of strategic detectors had one or more of these indicators. These values should not be used for calibrating Saturation Flow in a model, as they are not measured values.

It should also be noted that not all lanes have strategic detectors. This could be due to any of the following reasons:

- there is no detector;
- there is a detector but it spans more than one lane; or
- there is a separate detector in the lane but it is not important for the signal control system and therefore has not been set up as a strategic detector.

4. Factors that Affect Saturation Flow

Saturation Flow is not the same for all lanes. It will vary depending on the factors listed below. These factors will affect how Saturation Flow is experienced in the real world, the values of SCATS MF recorded and what values should be used in modelling.

As shown in *Figure 1*, it is useful to sub-divide these factors into those that are fixed and those that vary from cycle to cycle and at different times of day. The lane width, gradient, lane type and turn radius will not vary over time. Once known from the real world, these attributes can be input into the model and their effect on Saturation Flow taken into account consistently.

By contrast, the variable factors suggest that care should be taken when comparing a Maximum Flow rate measured in *one cycle* with Saturation Flow which is representative of *all cycles* in the analysis period. These effects are discussed further in *Section 7* below.

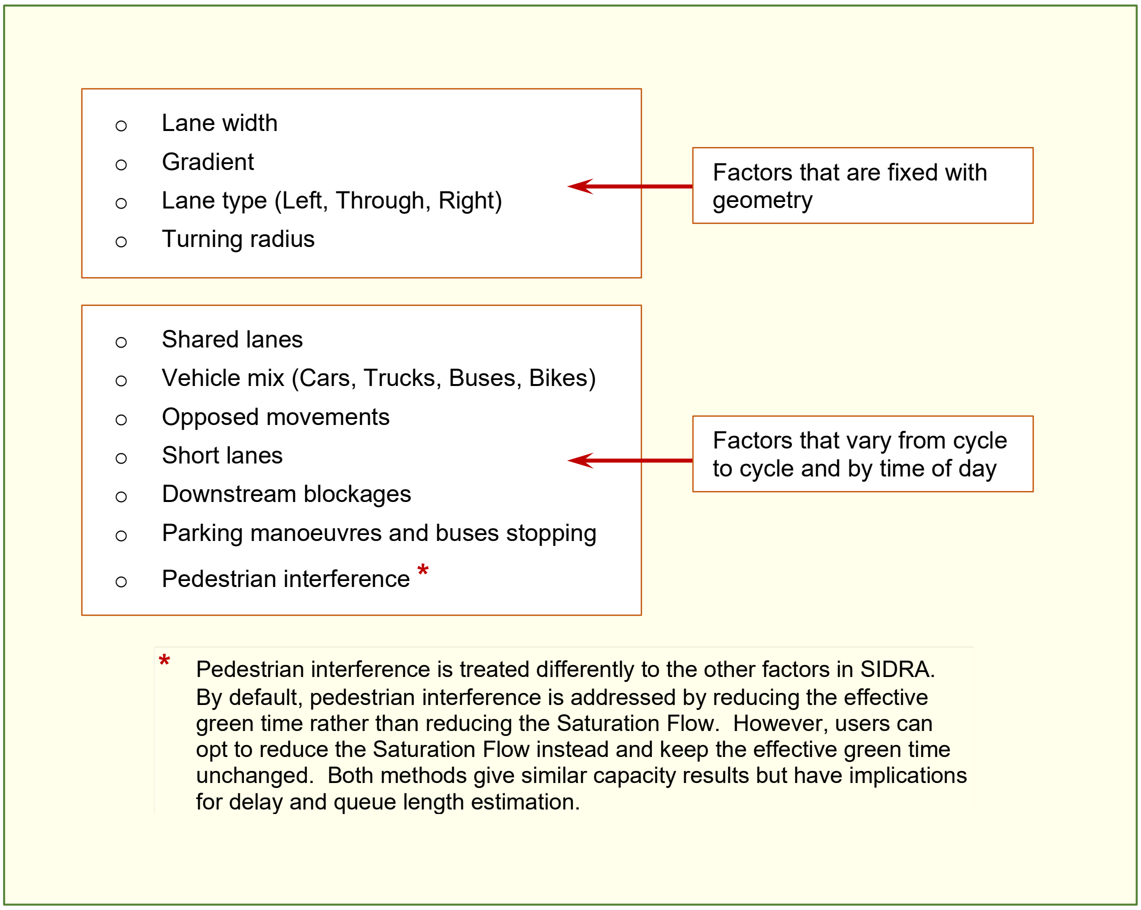

Figure 1 - Fixed and varying factors that affect Saturation Flow

5. Effective Green Time / Phase Time Factor

As shown in *Figure 2*, SCATS MF is measured over the full phase time, which includes the ***terminating intergreen*** (yellow plus all-red), or over the signal group green plus 5 seconds into the terminating intergreen.

Figure 2 also shows that the SIDRA Saturation Flow applies over the ***effective*** green time which excludes a ***start loss*** interval at the start of the displayed green period and adds an ***end gain*** interval at the end of the displayed green period. Generally, both the start loss and end gain are about 3 seconds.

Consider a saturated phase that runs 30 seconds of displayed green, 4 seconds yellow and 2 seconds all-red, as shown in *Figure 2*. Thus, the total phase time is 36 seconds. SCATS measures 15 vehicle detections and calculates the MF as 15 / 36 × 3600 = 1500 veh/h.

This is an underestimate of the Saturation Flow used in SIDRA, because in real life it is less likely that vehicles will cross the stopline during the last second of yellow and during the all-red interval. It is also unlikely that vehicles will cross the stopline during the first few seconds at the start of green at the full saturation flow rate while they are accelerating from stop to a saturation speed. In other words, the 15 vehicles would most likely have crossed the stopline during the 30 seconds of *effective* green (assuming start loss = end gain).

To adjust for this difference, the Saturation Flow for use in the model in this example should be 1500 / (30/36) = 1800 pcu/h. This means that the **SCATS MF** value needs to be divided by the **Effective Green / Phase Time Factor** to obtain the corresponding **Saturation Flow**.

What is important here is that the SIDRA model matches the real-world experience that a maximum of 15 passenger cars can get through this lane in a 36 second phase time. The capacity per cycle is estimated using SCATS MF as 36 × 1500/3600 = 15, which matches the capacity per cycle estimated using Saturation Flow as 30 × 1800/3600 = 15.

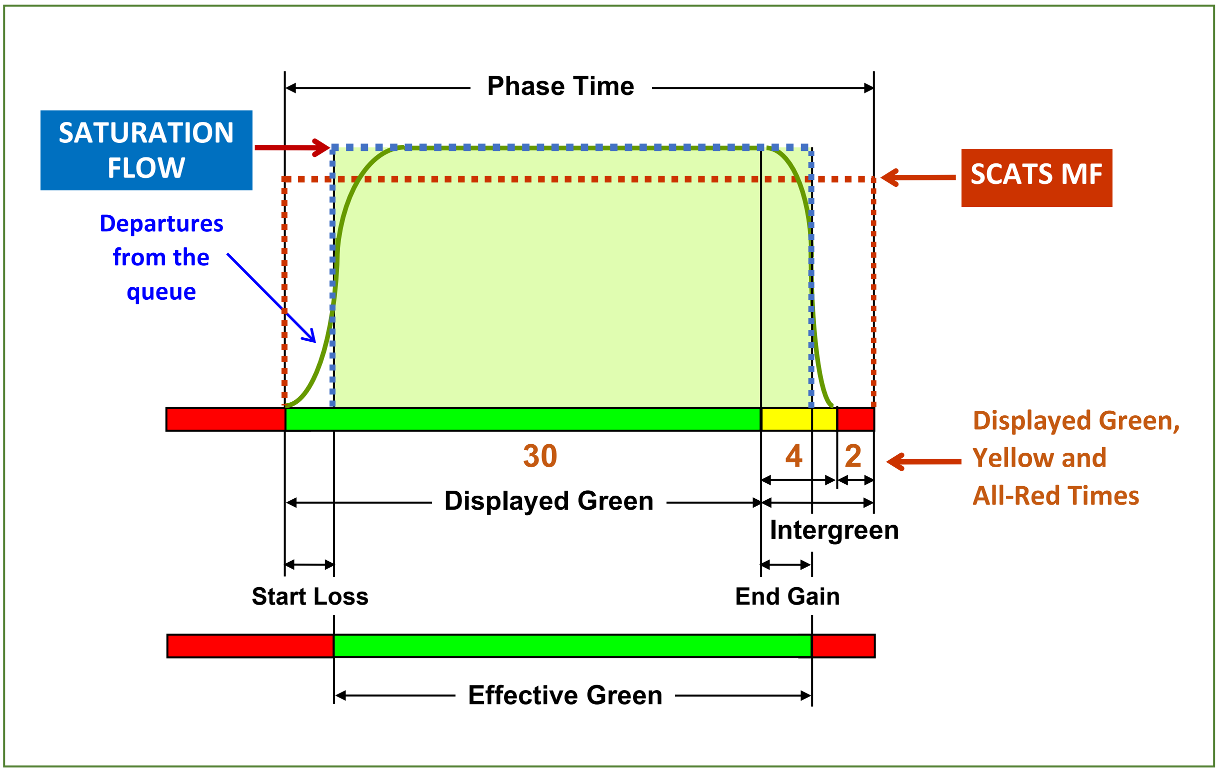

Figure 2 - Example to explain the Effective Green Time / Phase Time Factor

For detectors where the vehicle count is carried out over signal group green plus 5 seconds, a more accurate adjustment factor would be **Effective Green Time / (Displayed Green Time + 5 seconds)**. In a survey of three SCATS regions in Melbourne, the proportion of Strategic Inputs that collect over signal group rather than phase was 79%. It is therefore recommended that the **SIDRA Estimate of SCATS MF** should use the ratio of **Effective Green Time / (Displayed Green Time + 5 seconds)**. This would be more correct for the majority of cases.

Unless a saturation flow survey has been done, the user is blind to the “real” saturation flow rate and the typical duration of the *start loss* and *end gain*. If the SIDRA default values of 3 seconds for each of these parameters are used, the Effective Green Time is equal to the Displayed Green Time. However, the Effective Green Time in the conversion factor will differ from the Displayed Green Time if the user changes the *start loss* and *end gain* values in SIDRA.

6. SIDRA Estimate of SCATS MF

Although the calibration of SIDRA Saturation Flow to match SCATS MF is no longer recommended, SIDRA provides a **SIDRA Estimate of SCATS MF** to assist with the calibration process, should a user decide to do so. This is shown in the *SCATS Parameters* table in the *Detailed Output*. It is calculated by SIDRA as the **Basic Saturation Flow** adjusted for:

- Area Type Factor,
- Lane Width,
- Approach Grade,
- Saturation Flow Scale (from *Demand and Sensitivity* dialog; rarely used), and
- Turning Vehicle Factor,

but without the effects of:

- Parking manoeuvres,
- Buses stopping at bus stops,
- Movement Class (i.e. the mix of vehicles),
- Opposed turns (filtering),
- Short lane effects,
- Shared lanes with opposed turns or with movements that do not run in the same phases,
- Pedestrian interference,
- User-specified Capacity Adjustment, and
- Downstream queue blockage.

The **SIDRA Estimate of SCATS MF** corresponds to the “full saturation flow rate” for the given lane geometry. For lanes of normal width and level grade, the adjustment is likely to be just the **Turning Vehicle Factor**, for which the default values in SIDRA are 1.05 for a 90-degree turn, 1.2 for a sharp turn and 1.02 for a veering turn.

For shared lanes with unopposed movements that run in the same phase(s), a flow-weighted average **Turning Vehicle Factor** is used for through and turn movements in the lane. If the movements in a shared lane run in different phases, or if there is an opposed movement in the lane, SIDRA will not give a **SIDRA Estimate of SCATS MF**.

The adjusted Basic Saturation Flow value is reported in the SIDRA *SCATS Parameters* table in the column headed "**SCATS Satn Flow"**. It is then multiplied by the **Effective Green Time / Phase Time Factor** and reported in the column headed "**SCATS MF"** (Equation 8.1.7 in Section 8.1.2 of the SIDRA User Guide). For movements with two green periods, the SCATS MF is only estimated for the green period for which the estimated SCATS MF is higher.

There is a major problem with comparing MF recorded by SCATS with the **SIDRA Estimate of SCATS MF** in the *SCATS Parameters* table. The problem is that the user has no way of knowing at what time of day SCATS recorded the MF value. Therefore, it is impossible to say if the **Effective Green Time / Phase Time Factor** for the current analysis period is relevant for the MF recorded in SCATS. For example, if the phase runs for 36 seconds in the AM peak and 26 seconds in the PM peak, and the intergreen time is 6 seconds, should the applicable factor be 36/30 = 1.2 or 26/20 = 1.3? Or the MF may have been recorded in an off-peak period when the phase time was even shorter. This discrepancy could easily make a difference of 100 tcu/h or more in the Saturation Flow used in the model. For short phases, the discrepancy can be magnified considerably.

The problem of applying the **Effective Green Time / Phase Time Factor** is demonstrated in the Case Study in *Appendix A*.

7. Variable Effects on Saturation Flow

As mentioned above, there are some operational effects on Saturation Flow which vary from cycle to cycle and by time of day. These effects pose a problem for calibrating Saturation Flow against SCATS MF in a model. While SCATS MF is a record of the highest flow rate recorded for a single cycle, Saturation Flow in a model needs to be representative of the maximum flow rate achievable across all cycles in the analysis period. In other words, it needs to be an average of the Saturation Flow over all cycles in the analysis period.

As explained above, the **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores the variable factors other than flow proportions in some shared lanes. In most cases, correlating the **SIDRA Estimate of SCATS MF** with the actual recorded SCATS MF is based on the assumption that MF was recorded in a cycle where the variable factors were not present.

This is the best assumption that can be made because it is reasonably likely that the highest flow rate was recorded in a cycle with no parking manoeuvres, no buses stopping, no heavy vehicles, no opposed turns, no short lane effects, no pedestrian interference, no downstream blockages, and with mostly through traffic using a shared lane. However, these assumptions are false if no such cycle was experienced when flow rates were high.

Each of these variable effects is discussed in the sections below.

7.1 Parking Manoeuvres

Vehicles parking or unparking from kerbside parking spaces reduce the Saturation Flow for the adjacent traffic lane, even though these events may only occur occasionally. These events reduce the average Saturation Flow as it applies across the analysis period, but it is less likely that the SCATS MF was recorded in a cycle where one of these disruptions occurred. The **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor, i.e. it assumes that SCATS MF was recorded in a cycle when there were no kerbside parking manoeuvres.

7.2 Buses Stopping

Similar to parking manoeuvres, SIDRA reduces the Saturation Flow to account for occasional disruptions caused by buses stopping at a bus stop in the lane – either on the approach or departure side of the intersection. These events reduce the average Saturation Flow as it applies across the analysis period, but it is less likely that the SCATS MF was recorded in a cycle where one of these disruptions occurred. The **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor, i.e. it assumes that SCATS MF was recorded in a cycle when there were no buses stopping.

7.3 Heavy Vehicle (Movement Class) Effect

Correlating the **SIDRA Estimate of SCATS MF** with the recorded **SCATS MF** value assumes that the cycle in which MF was recorded consisted only of passenger cars. This is a best guess but may or may not be true. The **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor.

7.4 Opposed Turns

A lane that includes an opposed turn movement will often not have a recorded valid SCATS MF in the SCATS data. If there is a valid SCATS MF value, it is likely to have been recorded in a cycle where there was minimal opposing traffic. Again, the best assumption when correlating the **SIDRA Estimate of SCATS MF** with the recorded SCATS MF would be to assume that there was no opposing traffic in the cycle when SCATS MF was recorded, but this is not guaranteed. Therefore, the **SIDRA Estimate of SCATS MF** is not given for exclusive and shared lanes with opposed turns.

7.5 Short Lane Effects

(a) Approach short lanes

The short lane effect comes into play if the effective green time is sufficient to discharge a queue longer than the short lane storage length. The effect may apply to both the short lane and its overflow lane. It is likely that SCATS MF was recorded in a cycle when the short lane effect was at a minimum, either because the green time was shorter than the time needed to discharge the queue in the short lane, or because most of the traffic beyond the short lane length decided to use one lane rather than the other. Again, the accuracy of the correlation depends on this assumption. The **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor, i.e. it assumes that SCATS MF was recorded in a cycle when there was no short lane effect.

(b) Exit short lanes

This is handled in SIDRA by reducing the **Lane Utilisation Ratio** instead of reducing the Saturation Flow. If a valid MF has been recorded by SCATS, it is unlikely to represent fully saturated flow. The **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor, i.e. it assumes that SCATS MF was recorded in a fully saturated green period.

7.6 Shared Lanes

There are many types of shared lanes and the correlation between SCATS MF and Saturation Flow will range from reasonably valid to very problematic.

The first case to consider is a shared through and right turn lane where both movements are unopposed and always run together in the phase sequence (i.e. both movements receive green at the same time), such as in a split phase arrangement. In this case, the **SIDRA Estimate of SCATS MF** is based on a flow-weighted average Turning Vehicle Factor. The source of error is in the proportion of traffic flows in the lane. It is most likely that SCATS records MF in a cycle during which there was a high proportion of through traffic, as we know empirically that headways are shorter for through movements than for turning movements. There will be some error in the correlation since it is likely that the average proportion of right turners in the SIDRA model will vary significantly from the proportion in the cycle when MF was recorded by SCATS.

If the movements in the shared lane run in different phases, a **SIDRA Estimate of SCATS MF** will not be given. In this case, SIDRA applies a "lane interaction" model to estimate the average saturation flow and effective green time for the lane allowing for blocking of movements by each other at different times during the phases involved (the method is based on a paper by Hegarty and Pretty 1982). As a result, the **SIDRA Estimate of SCATS MF** is not likely to be a reliable one in this case.

The other case to consider is a shared lane with through and opposed right turns which run in the same phase. There is no right turn phase, and the right turn movement must filter. If the lane is running at full capacity, the flow rate will vary a lot from cycle to cycle depending on the number of vehicles turning right and the gaps in the opposing traffic during each cycle. It is likely that SCATS records MF in a cycle with favourable conditions, which could occur in the off-peak when the phase time is a lot shorter than during the peaks. There will be many cycles in which the flow rate does not meet the SCATS eligibility criteria. For this type of shared lane, the SCATS MF is of little use in estimating the hourly average Saturation Flow for use in a model, and therefore, a **SIDRA Estimate of SCATS MF** will not be given for lanes with opposed turns.

7.7 Effect of Pedestrian Interference

This effect applies particularly to left turns giving way to pedestrians, but equally applies to any movement opposed by pedestrians.

In the real world, cycles in which left turners give way to pedestrians will experience a lower saturation flow rate. It is likely that SCATS MF was recorded in a cycle where there were no pedestrians or relatively few pedestrians.

The SIDRA default method to model pedestrian effects on capacity is to apply an additional *start loss* for the left turn movement, which reduces the effective green time, rather than reducing the Saturation Flow. However, there is an option in the **Gap Acceptance** dialog to reduce Saturation Flow instead. Both methods give similar capacity results.

When applying the **Effective Green Time / Phase Time Factor** in SIDRA, the effective green time is not reduced by the additional *start loss* due to pedestrian interference. If the Saturation Flow Adjustment option is selected by the SIDRA user, the SCATS MF given in the *SCATS Parameters* table corresponds to the "full saturation flow rate". For both methods, the **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor, i.e. it assumes that SCATS MF was recorded in a cycle when there was no pedestrian interference.

7.8 Downstream Queue Blockage

Like parking manoeuvres and bus stops mentioned above, downstream blockages are unlikely to occur every cycle in an analysis period. SIDRA applies a capacity reduction as a function of downstream queue blockage probability. However, the **SIDRA Estimate of SCATS MF** is based on a Saturation Flow value which ignores this variable factor, i.e. it assumes that SCATS MF was recorded in a cycle when there was no downstream queue blockage.

8. Does SCATS MF Represent Full Saturation?

SCATS MF is the maximum flow rate recorded for a lane in a cycle. However, the measured maximum flow rate recorded by SCATS does not necessarily represent a fully saturated green period. If the demand never quite reaches capacity, but the flow rate in a cycle is still high enough to meet the SCATS eligibility criteria, a valid SCATS MF will be recorded but this will be lower than the true Saturation Flow.

As part of this investigation, SCATS MF data were collected from the Blackburn, Glen Iris and Carlton2 regional computers in the Melbourne metropolitan area. The valid SCATS MF values without any of the #, * or + symbols (discussed in *Section 3*) were plotted into histograms, as seen in *Figure 3*.

Across all three regions, the values range from 1047 to 2368 veh/h. A reasonable proportion of the values are a lot less than would be expected from fully saturated flow. As a guide, 7% are less than 1300 veh/h. Low values could be due to two possible causes:

- A low value could be because the highest flow rate was high enough to meet the eligibility criteria, but the demand was not enough to reach fully saturated flow in any cycle. In such a case, the value should not be used to calibrate a model as it does not represent the full Saturation Flow.
- Alternatively, the lane could have been operating at full capacity, but there was some effect that reduced the flow rate that remained present in the cycle when SCATS MF was recorded. This could be any of the variable effects, such as the short lane effect, shared lane effect, presence of heavy vehicles, or pedestrian interference. For this case, calibrating this low value to the **SIDRA Estimate of SCATS MF** (which takes into account only the fixed geometric factors) would result in double counting the variable effects in the model.

It is difficult for the user to distinguish between these two possible causes without an extensive survey. Whatever the cause, calibrating Saturation Flow to a low value of SCATS MF would result in an underestimate of the true capacity of the lane in the model. The difficulty is that there is no clear threshold at which the SCATS MF would be regarded as too low.

There are many examples of SCATS MF being different in adjacent lanes which have the same characteristics (same width, same gradient, same approach and exit conditions), and no reason why the vehicle mix should be different. The only explanation is that one lane simply does not reach fully saturated conditions. Examples are given in *Appendix B*.

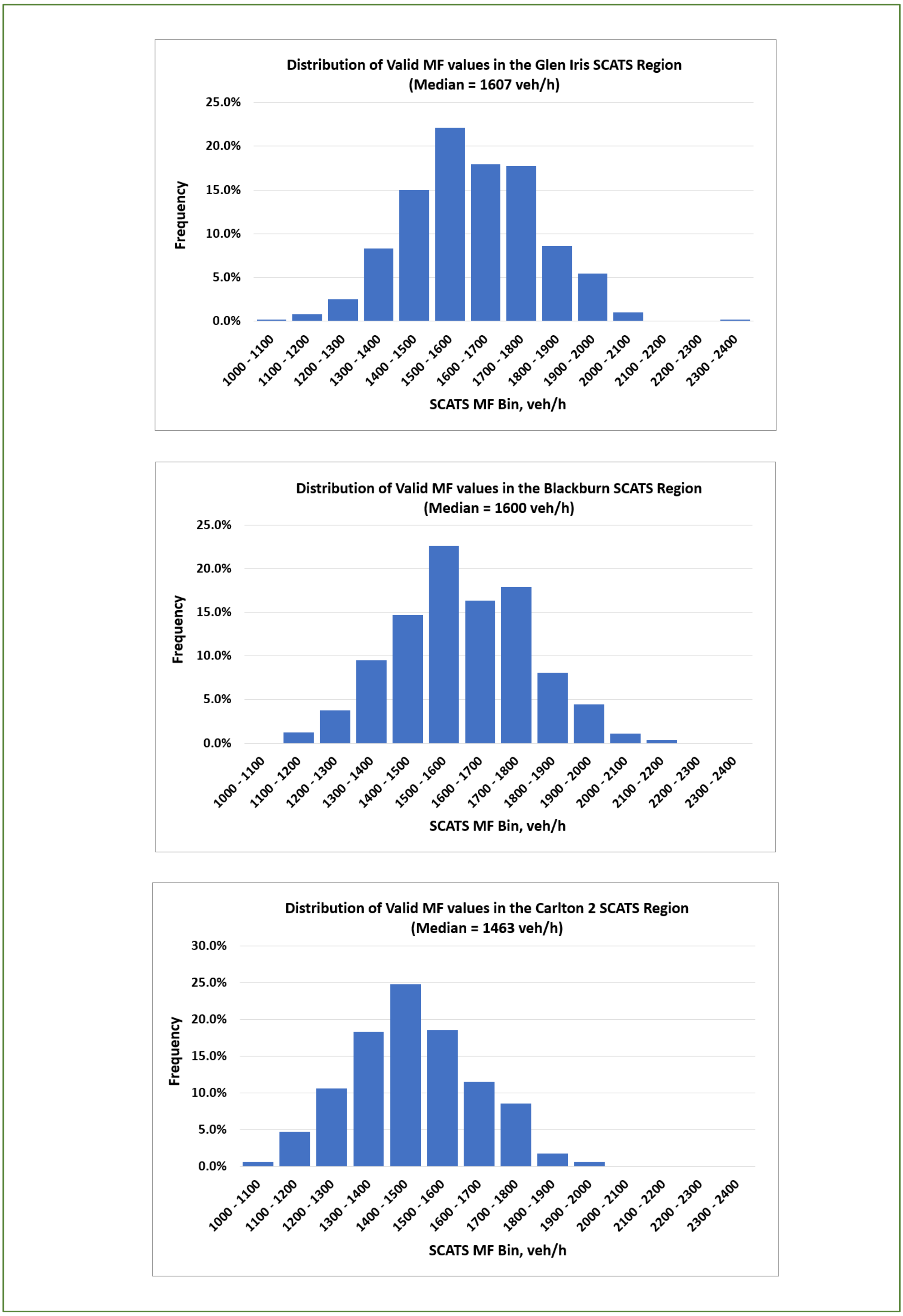

Figure 3 - Valid SCATS MF data collected from the Blackburn, Glen Iris and Carlton2 regional computers in the Melbourne metropolitan area

9. Correlation from Previous Research

The correlation between Saturation Flow and SCATS MF was examined in the ARRB Research Report ARR340 (Akçelik, Besley and Roper 1999).

Across five intersections in Sydney and six intersections in Melbourne, there were seven through lanes and four right turn lanes examined. The SCATS MF values were compared with a calculated parameter called Analytical S_{MF} which was based on the observed survey results, as summarised in *Table 1*.

A linear regression analysis between recorded SCATS MF and Analytical S_{MF} showed a correlation coefficient of $R^2 = 0.77$ as seen in *Figure 4*.

Although the correlation looks reasonable, S_{MF} was calculated from the *known* maximum green time recorded on the survey day. The SCATS MF values may or may not have been recorded in the same cycle that maximum green time occurred. But it is much more likely to be close to the green time when MF was recorded. In the SIDRA model, on the other hand, there is no knowledge of the range of green times for each movement during the day. The model can only use the **Effective Green Time / Phase Time Factor** for the *current* analysis period, or the user must simply guess the relevant phase time.

Furthermore, the sites and lanes chosen in ARR340 are not a representative sample of lane types. There were no left-turn-only lanes and no shared through-and-right lanes. Site 3196 was the only one which was shared through-and-left. The right turn pockets were quite generous, so the short lane effects were small. Pedestrian interference effects were only present at one intersection (Site 3196). All these lanes were fully saturated at some times during the day, so it is unlikely that any of them would have low MF due to under-utilisation.

In addition, traffic count data was only processed for the cycles in which there were no heavy vehicles present.

The comparisons given in ARR340 were within a controlled survey environment. They indicate the best level of correlation possible between SCATS MF and Saturation Flow. For normal modelling tasks, without the benefit of detailed survey data, the correlation is unlikely to be as good.

Table 1: Correlation between SCATS MF and a corresponding calculated parameter

Site	City	Recorded SCATS MF	Analytical S_{MF}
Through Lanes			
1081	Sydney	1818	1667
413	Sydney	1714	1702
511	Sydney	2156	2156
3196	Melbourne	1905	1663
4273	Melbourne	1827	1774
849	Melbourne	2034	1808
456	Melbourne	2236	2166
Right Turn Lanes			
163	Sydney	1895	1804
610	Sydney	1579	1612
121	Melbourne	1925	1734
335	Melbourne	1915	1790

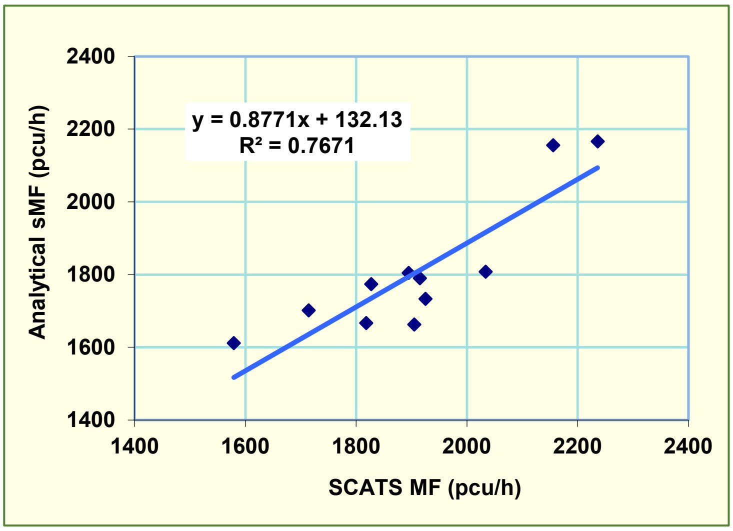

Figure 4 - Correlation between SCATS MF and S_{MF} from ARR340

10. Summary of Calibration Problems

SCATS MF is only available for *existing* signalised intersections and cannot be used directly for *proposed* intersections.

For existing signalised intersections, valid SCATS MF values may not be available for every lane. This is because not all lanes at existing intersections have strategic detectors, and from the survey described in *Section 3*, 38% of strategic detectors have SCATS MF values that are not valid measured values.

Even if perfect calibration of Saturation Flow could be achieved in a model using the SCATS MF values for an existing signalised intersection, the application of the model to a future scenario may involve some very different lane geometry, phasing, timing and operational characteristics, and therefore, the existing SCATS MF values may not be applicable to future conditions.

Where there is a valid SCATS MF value, there are five reasons why correlation with Saturation Flow may not be reliable:

(a) SCATS MF does not necessarily represent fully saturated flow conditions even though it meets the SCATS criteria for being recorded as a valid MF value. This means that SCATS MF can underestimate the "true" Saturation Flow for underutilised lanes.

(b) SCATS MF is recorded for the cycle in which conditions were the best. This is not necessarily representative of average Saturation Flow for the analysis period. For lanes subject to variable effects, such as pedestrian interference, short lane effects, downstream queue blockage, shared lane effects or variable heavy vehicle proportions, the SCATS MF can overestimate the "true" Saturation Flow for the analysis period.

(c) SCATS MF may have been recorded at a different time of day to the analysis period, when the variable effects were significantly different. For example, parking conditions might be very different at different times during the day.

(d) SCATS MF is measured over Phase Time (or Signal Group Green + 5 seconds) which does not correspond to effective green time. This is an intractable problem because there is no record of the phase time when SCATS MF was recorded.

(e) SCATS MF differs from Saturation Flow for short green periods significantly because the **Effective Green Time / Phase Time Factor** is too low in such cases. This is particularly relevant to turning movements controlled by a green arrow.

The Case Study given in *Appendix A* demonstrates problem (e) above. The adjustment of the SIDRA **Basic Saturation Flow** to match the recorded SCATS MF values resulted in unrealistically high modified Basic Saturation Flow leading to high SIDRA Saturation Flow values for most movements. The values above 2200 veh/h are highlighted in orange colour in *Table A1*. In particular, because of the short phase times for the right turn movements, the application of low values of **Effective Green Time / Phase Time Factor** resulted in very high values of Saturation Flow. The values above 2500 veh/h are highlighted in red colour in *Table A1*. For example, a Saturation Flow of 3072 veh/h for the West right turn movement (about 8 vehicles departing in 9 seconds) is highly unlikely and undermines the credibility of the method.

Another problem with the use of SCATS MF for calibrating Saturation Flow is that the **SIDRA Estimate of SCATS MF** will not stay the same when SIDRA is allowed to calculate signal timings using the modified Basic Saturation Flow values as shown in the case study given in *Appendix A*. These issues indicate that a stable relationship between Saturation Flow and SCATS MF is not possible since this depends on the **Effective Green Time / Phase Time Factor** which is likely to vary when signal timings are calculated by SIDRA for different scenarios of intersection geometry and demand flows for current and future traffic.

11. Basic Saturation Flow Research Results

If it is considered that a reasonable range of Saturation Flows should not vary from the SIDRA default **Basic Saturation Flow** value of 1950 tcu/h by more than 30 percent, the range is around 1400 to 2500 tcu/h. The US Highway Capacity Manual (TRB 2022) specifies a Basic Saturation Flow value of 1900 tcu/h. *Table 2* gives the Basic Saturation Flow values reported in ARR340 (Akçelik, Besley and Roper 1999) which are in the range 1786 to 2549 tcu/h. These are based on surveys at 18 intersections in Melbourne and Sydney.

The SIDRA default Saturation Flow value of 1950 tcu/h is based on research conducted by Cuddon (1993, 1994). This research data comprised over 40,000 saturation headways collected in 163 lanes at 71 sites in the Melbourne Metropolitan area. The results summarised in *Table 3* (copied from Cuddon 1993) are in the range 1577 to 2505 tcu/h. This table shows the value of 1950 tcu/h for Environment Class 1 (Good conditions) recommended for SIDRA based on values in the range 1849 to 2081 tcu/h. Before adopting this value, earlier versions of the software used 1850 tcu/h based on ARR123 (Akçelik 1981; Miller 1968a,b). Austroads (2020) Guide to Traffic Management Part 3: Transport Study and Analysis Methods, Table 7.4 uses the value of 1850 tcu/h as in earlier versions of SIDRA.

Table 3 includes results for Environment Classes 2 (Average) with values in the range 1577 to 1976 tcu/h and 5 (Very Good) with values in the range 1938 to 2055 tcu/h. Interestingly, Cuddon (1993) noted that no data were observed for Environment Classes 3 (Poor) and 4 (Very Poor). By extrapolating the data, he stated 1625 tcu/h for Environment Class 3 and 1460 tcu/h for Environment Class 4.

In contrast with Cuddon's research, the "Base Saturation Flows" given in Table 2 of a paper by Laufer, et al (2019) appear to be very low. For example, the values for Primary Roads are in the range 1425 to 1700 (units not stated). The paper states that these values were derived by selecting the Maximum Flow from all signal cycles within 24 hours and then reducing the selected value by 5% to be used as the Base Saturation Flow Rate. The method used in the paper by Laufer, et al (2019) appears to be adopted in several tables in the DOT Victoria (2020) Draft Transport Modelling Guidelines Volume 5 - Intersection Modelling, Section 7.2.4. As such, these values are subject to the problems associated with the use of SCATS MF for calibration purposes discussed in *Section 10*. Therefore, it is strongly recommended that these values should not be used as Basic Saturation Flow values in SIDRA.

Table 2: Saturation flow and associated parameters based on light vehicle data observed at 18 intersections in Melbourne and Sydney, Australia

Site	Sat. flow s (veh/h)	h_s (s) (2)	Start loss t_s (s)	End gain t_e (s)	Sat. speed v_s (km/h)	Speed limit v_f (km/h)	Speed ratio v_s/v_f	Jam spacing L_{hj} (m)	Resp. time t_r (s)	Ave. Accel. rate, a_a (m/s^2)	Max. accel. rate, a_m (m/s^2)
ALL SITES (Thru and RT)	**2070**	**1.739**	**2.4**	**2.6**	**38.2**	**68**	**0.56**	**6.8**	**1.06**	**1.53**	**2.64**
Through (Isolated) Sites											
Average	**2112**	**1.705**	**2.8**	**2.6**	**45.1**	**69**	**0.65**	**7.0**	**1.15**	**1.65**	**2.85**
Sydney 3	**1786**	2.015	2.9	3.0	39.5	60	0.66	6.8	1.40	1.43	2.45
Sydney 4	**1801**	1.999	1.8	3.0	33.2	60	0.55	6.8	1.26	1.67	2.87
Sydney 5	**2278**	1.580	3.4	2.4	52.8	70	0.75	6.6	1.13	1.62	2.83
Melbourne 3	**1885**	1.909	2.7	2.9	31.7	60	0.53	7.0	1.11	1.19	2.03
Melbourne 4	**1933**	1.863	2.8	2.8	34.0	60	0.61	7.3	1.14	1.33	2.28
Melbourne 5	**1995**	1.805	2.8	2.7	44.0	70	0.66	6.9	1.27	1.70	2.93
Melbourne 6	**2416**	1.490	2.6	2.2	53.8	80	0.67	7.0 (3)	1.02	2.08	3.62
Melbourne 7	**2549**	1.412	2.9	2.1	51.0	80	0.70	7.0 (3)	0.96	1.94	3.39
Melbourne 8	**2418**	1.489	2.8	2.2	42.0	80	0.58	7.0 (3)	0.94	1.68	2.91
Melbourne 9	**2208**	1.630	3.4	2.4	47.9	60	0.80	7.0 (3)	1.10	1.49	2.58
Melbourne 10	**1963**	1.834	2.6	2.8	52.4	80	0.66	7.2 (3)	1.35	2.01	3.49
Through (Closely-Spaced) Sites											
Average	**1965**	**1.832**	**1.9**	**2.8**	**30.9**	**67**	**0.46**	**7.0 (3)**	**1.02**	**1.49**	**2.55**
Melbourne 11	**1981**	1.817	1.9	2.7	30.9	60	0.52	7.0 (3)	1.00	1.48	2.54
Melbourne 12	**1804**	1.996	1.5	3.0	27.1	60	0.45	7.0 (3)	1.07	1.48	2.53
Melbourne 13	**2110**	1.706	2.2	2.6	34.6	80	0.43	7.0 (3)	0.98	1.51	2.60
Right-Turn (Isolated) Sites (1)											
Average	**2034**	**1.770**	**1.7**	**2.7**	**24.5**	**65**	**0.38**	**6.4**	**0.84**	**1.23**	**2.10**
Sydney 1	**2096**	1.717	1.6	2.6	24.7	60	0.41	6.0	0.84	1.34	2.29
Sydney 2	**1965**	1.832	1.4	2.7	21.7	60	0.36	5.9	0.85	1.23	2.09
Melbourne 1	**1946**	1.850	1.8	2.8	24.4	70	0.35	6.6	0.88	1.17	2.00
Melbourne 2	**2130**	1.690	2.1	2.5	27.1	70	0.39	6.9	0.77	1.18	2.02

All parameters in this table are for light vehicles only.

(1) Left-turn for driving on the right-hand side of the road.

(2) h_s = 3600 / s.

(3) Nominal values (jam spacing was not measured during these early surveys except at Melbourne 10 site where L_{hj} = 7.2 m was measured).

Sydney 3 : 9 percent uphill grade.

Melbourne 3 : Shared through and left turn (15 per cent left turn).

Melbourne 4 : 6 percent uphill grade.

Source:
AKÇELIK, R., BESLEY M. and ROPER, R. (1999). *Fundamental Relationships for Traffic Flows at Signalised Intersections.* Research Report ARR 340. ARRB Transport Research Ltd, Vermont South, Australia.

Table 3: Basic Saturation Flow statistics by Environment Class

	Observed Saturation Flow (Veh/h)	Basic Saturation Flow		
		Adjusted for HVs	Proposed for SIDRA	ARR 123
Environment Class 1 (Good)				
No. of Lanes	27	27		
Minimum	1638	1849		
Maximum	2032	2081		
Average	**1926**	**1957**	**1950**	**1850**
Std. Dev.	58.5	55.6		
Environment Class 2 (Average)				
No. of Lanes	28	28		
Minimum	1547	1577		
Maximum	1951	1976		
Average	**1758**	**1786**	**1775**	**1700**
Std. Dev.	94.3	97.3		
Environment Class 5 (Very Good)				
No. of Lanes	41	41		
Minimum	1878	1938		
Maximum	2476	2505		
Average	**2113**	**2164**	**2150**	**2000**
Std. Dev.	146.5	143.4		

Notes:

- There were no data for Environment Classes 3 (Poor) and 4 (Very Poor).
- Observed Saturation Flow values were converted to Basic Saturation Flow values using the Heavy Vehicle equivalent of 1.65 tcu/veh determined from the surveys (Cuddon and Ogden 1992).
- The proposed Basic Saturation Flows for the mean values were rounded to the nearest multiple of 25 tcu/h.

Source:
CUDDON, A.P. (1993). Lane Saturation Flows at Signalised Intersections in Melbourne. PhD Thesis. Department of Civil Engineering, Monash University. Melbourne, Australia.

12. Recommended Modelling Practice

To ensure greater confidence and consistency in modelling, calibrating Saturation Flow against SCATS MF is not recommended.

Models should be run initially with an accepted global value of **Basic Saturation Flow** for the relevant area (e.g. for a city). It is justifiable to have different **Basic Saturation Flow** values in different cities to acknowledge inherent differences in driver behaviour. This could be the case between large cities, like Sydney and Melbourne, compared to smaller cities, like Adelaide, Hobart and Canberra. There could also be differences between large cities and those in regional areas. Extensive surveys would need to be undertaken to establish these differences.

Meanwhile, the SIDRA default value of 1950 tcu/h has been determined from several studies in Australian cities and serves as a good, consistent starting point (*Section 11*).

The **Apply Saturation Flow Estimation** parameter in the **Lane Data** tab of the **Lane Geometry** dialog should remain checked ☑ so that SIDRA can adjust the Saturation Flow for the lane characteristics of the base model, as well as any subsequent changes in the base model for future or alternative scenarios. Thus, Saturation Flow values should not be locked in; they need to vary in the SIDRA model if there are any changes to vehicle demand, pedestrian demand, geometry or phasing.

It is recommended that models be calibrated and validated against observed performance measures. These could be average back-of-queue lengths, queue lengths at start of green, average delays, travel times or average speeds. This process involves adjusting **Basic Saturation Flow** in the model – either directly for each lane, or on an approach basis through the **Area Type** factor. The SCATS MF values for through lanes may provide some guidance for this calibration and validation process.

13. Comparison of Saturation Flow and SCATS MF

Although it is not recommended to calibrate Saturation Flow with SCATS MF, there may be some interest in researching the correlation between them. For this purpose, it is recommended that the comparison is <u>only</u> done for lanes where:

- SCATS SI data do not have a #, * or + symbol for that detector (see *Section 3*);
- it is not a filter only right turn lane where departures are by gap acceptance process;
- if it is a shared lane, the movements from that lane run in the same phase (or phases) and are unopposed;
- if it is a short lane, or adjacent to a short lane, the length of the short lane is enough for the short lane effect to be negligible;
- the lane has good lane discipline in the vicinity of the detector loops (i.e. vehicles do not straddle the lane line);
- the lane is not a slip / bypass lane where departures by gap acceptance process are involved.

Steps should be taken to estimate the Phase Time which was operational when SCATS MF is likely to have been recorded. This Phase Time should be used to determine the **Effective Green Time / Phase Time Factor** to obtain the corresponding **Saturation Flow**. This is important to avoid amplifying any miscalculation or abnormal SCATS MF measurement.

Care must be taken if the lane operates under different conditions throughout the day. Examples are:

- a movement is allowed from the lane at some times of the day but is banned at other times;
- parking is banned at some times of day but not at other times;
- the phasing changes during the day;
- the proportion of vehicles doing the movements from a shared lane varies significantly throughout the day.

14. Conclusions

The investigations reported in this document found the use of SCATS MF to calibrate Saturation Flow to be problematic. It is shown that valid values of SCATS MF are not available for many lanes, and where they are available, there are serious problems in translating SCATS MF to a reliable Saturation Flow value. Consequently, it is recommended that SCATS MF should not be used to calibrate SIDRA models.

Greater confidence and consistency in modelling can be achieved by starting with standard values of Basic Saturation Flow and then calibrating and validating the model against observed performance measures such as average back-of-queue length, queue length at start of green, average delay, travel time or average speed. This process can be implemented by adjusting the **Basic Saturation Flow** in the model. A limited use of SCATS MF values for through movement lanes may provide some guidance in this calibration and validation process.

It is recommended that Austroads Guide to Traffic Management Part 3 (Transport Study and Analysis Methods) adopts the current SIDRA default Basic Saturation Flow value of 1950 tcu/h and the associated Environment Class table as discussed in *Section 11* to replace the older values.

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Appendix A – Case Study: Springvale Road / Canterbury Road

The intersection of Springvale Road / Canterbury Road in Forest Hill, Melbourne was chosen as a case study to see the effects of calibrating Saturation Flow to match SCATS MF.

This intersection is typical of a large arterial intersection, with left turn slip lanes on all corners and separate right turn lanes on all approaches. There are no shared lanes and no signalised movements are in conflict with pedestrians. The intergreen times are all 7 seconds. An unusual feature of this intersection is that there are two lanes on the West and East approaches that have not been set up as strategic detectors in SCATS.

The SCATS MF values, as recorded in April 2021, are shown in *Figure A1*.

An aerial photo is shown in *Figure A2*.

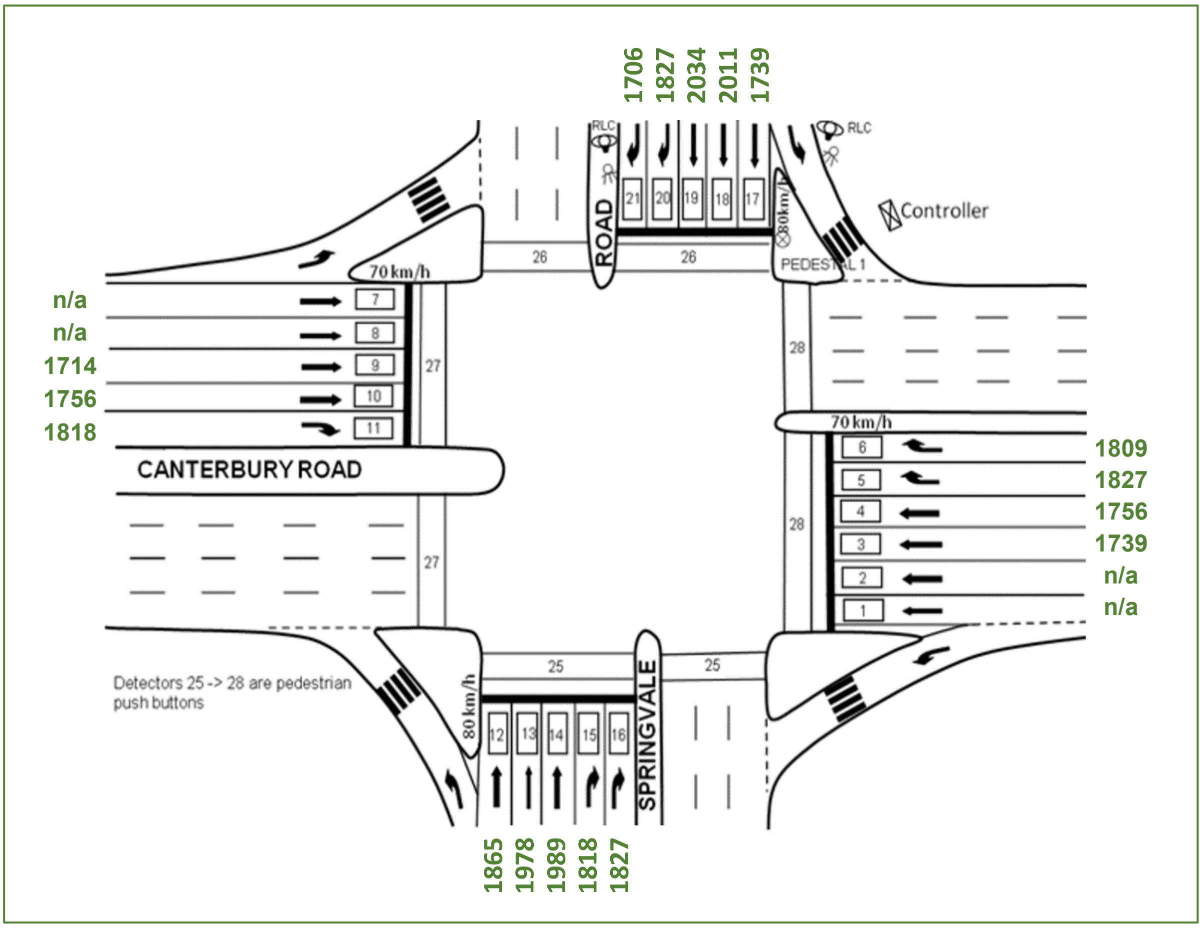

Figure A1 - Layout diagram for Springvale Rd / Canterbury Rd and SCATS MF values

Figure A2 - Aerial photo of Springvale Rd / Canterbury Rd

The process of calibrating the SIDRA **Basic Saturation Flow** to match the SCATS MF is shown in *Table A1*.

The default value of **Basic Saturation Flow** is 1950 tcu/h. For this intersection, there is no adjustment for lane width or gradient. In this case, the **SIDRA Estimate of SCATS MF** is effectively the **Basic Saturation Flow** default value divided by the **Turning Vehicle Factor** and multiplied by the **Effective Green Time / Phase Time Factor**.

For calibration, the **Basic Saturation Flow** (col.5) is multiplied by the ratio:

Recorded SCATS MF (col.4) **/ SIDRA Estimate of SCATS MF** (col.9)

so that the **Revised SIDRA Estimate of SCATS MF** (col.11) matches the **Recorded SCATS MF** (col.4).

The **Modified Basic Saturation Flow** (col.10) is input to the SIDRA program, which then applies the necessary saturation flow adjustments. In this case study, these consist of the **Turning Vehicle Factor**, heavy vehicle factor and short lane effects. The resulting **SIDRA Saturation Flow** values (col. 12) are used in capacity and performance calculations.

SIDRA was used to analyse different cases, as shown in *Table A2*. In all cases, the cycle time was 128 seconds.

Table A1 – Calibration Process for Springvale Rd / Canterbury Rd Case Study (Results from SIDRA Version 9.1.1.200)

Approach (1)	SIDRA Lane Number (2)	SCATS Detector Number (3)	Recorded SCATS MF (4)	SIDRA Basic Satn Flow (5)	Turn Factor (6)	Effective Green Time (7)	Phase Time (8)	SIDRA Estimate of SCATS MF (9)	Modified Basic Satn Flow (10)	Revised SIDRA Estimate of SCATS MF (11)	SIDRA Satn Flow (as used in calcs) (12)
SOUTH	1	Slip	NA								
	2	12	1865	1950	1	39	46	1653	2200	1865	2133
	3	13	1978	1950	1	39	46	1653	2333	1978	2262
	4	14	1989	1950	1	39	46	1653	2346	1989	2240*
	5	15	1818	1950	1.05	11	18	1135	3124	1818	2877
	6	16	1827	1950	1.05	11	18	1135	3139	1827	2891
EAST	1	Slip	NA	1950							
	2	1	NA	1950	1	34	41	1617		1617	1862
	3	2	NA	1950	1	34	41	1617		1617	1728*
	4	3	1739	1950	1	34	41	1617	2097	1739	2002
	5	4	1756	1950	1	34	41	1617	2118	1756	2022
	6	5	1827	1950	1.05	24	31	1438	2478	1827	2243
	7	6	1809	1950	1.05	24	31	1438	2453	1809	2221
NORTH	1	Slip	NA	1950							
	2	17	1739	1950	1	46	53	1692	2004	1739	1572*
	3	18	2011	1950	1	46	53	1692	2317	2011	2250
	4	19	2034	1950	1	46	53	1692	2344	2034	2107*
	5	20	1827	1950	1.05	18	25	1337	2664	1827	1911*
	6	21	1706	1950	1.05	18	25	1337	2488	1706	1846*
WEST	1	Slip	NA	1950							
	2	7	NA	1950	1	19	26	1425		1425	1862
	3	8	NA	1950	1	19	26	1425		1425	1862
	4	9	1714	1950	1	19	26	1425	2345	1714	2239
	5	10	1756	1950	1	19	26	1425	2403	1756	2294
	6	11	1818	1950	1.05	9	16	1045	3394	1818	3072

* Saturation flow reduced due to short lane effect

Table A2 – Case Study Results of SIDRA Analyses

Case	Deg. of Satn	Average Delay	Description	
Case 1	0.901	57.8	Default Basic Saturation Flow of 1950 tcu/h	
Case 2	0.845	48.8	Adjust Basic Saturation Flow to match SIDRA estimate of MF with SCATS MF; phase times specified as calculated in Case 1	
Case 3	0.754	46.5	As in Case 2 but with user-given cycle time and phase time calculations	
Case 4	0.753	46.5	As in Case 3 but with Basic Saturation Flow adjusted for detectors 1, 2, 7 & 8	
Case 5	0.939	65.4	MF input as Basic Saturation Flow; Saturation Flow estimation enabled	NOT RECOMMENDED
Case 6	0.866	55.2	MF input as Basic Saturation Flow; Saturation Flow estimation disabled	

In Case 1, normal SIDRA calculations were implemented using the default Basic Saturation Flow value of 1950 tcu/h for all lanes. Cycle time was user-given as 128 seconds based on a previous study of this intersection. Phase times were calculated by SIDRA according to the EQUISAT principle. These signal timings were used in lieu of observed timings as required for calibration purposes. In *Table A1*, the resulting values of **Effective Green Time**, **Phase Time** and **SIDRA Estimate of SCATS MF** are given in columns 7, 8 and 9.

For Case 2, the phase times from Case 1 were input as user-given values. This avoids the effect of changes in calculated phase times on the SCATS MF estimate. In *Table A1*, the resulting values of **Modified Basic Saturation Flow**, **Revised SIDRA Estimate of SCATS MF** and **SIDRA Saturation Flow** (used in capacity and performance calculations) are given in columns 10, 11 and 12. The values of the **Effective Green Time / Phase Time Factor** used for adjusting the Basic Saturation Flow varied between 0.73 and 0.87 for Through movement lanes and between 0.56 and 0.77 for Right Turn movements.

In Case 3, the **Modified Basic Saturation Flow** values remained as determined in Case 2 (col. 10 in *Table A1*) but the program was permitted to adjust the Phase Times for a user-given cycle time of 128 s. When SIDRA is permitted to adjust the phase times, any change to Saturation Flows could change the phase times, which, in turn, changes the **SIDRA Estimate of SCATS MF**. Effective Green Times in Case 3 differed from those in Case 2 in the range -2 to +4 seconds. Changes were observed for a large proportion of the estimated SCATS MF values in Case 3 for this reason.

Case 4 emulated the more common scenario where all lanes have been set up with strategic detectors. **Basic Saturation Flow** values were set to the same values as the adjacent through movement lanes in Cases 2 and 3. As in Case 3, the program was permitted to adjust the phase times for a user-given cycle time of 128 s. Changes to **Basic Saturation Flows** for detectors 1, 2, 7 and 8 led to Phase Times that differed from both Cases 2 and 3. As a result, the **SIDRA Estimated SCATS MF** values differed from Case 2 which was calibrated for **Recorded SCATS MF** values using the same phase times as in Case 1.

In Cases 5 and 6, the SCATS MF value was input directly as the **Basic Saturation Flow** in SIDRA. The program calculated the phase times for a user-given cycle time of 128 s. This method is NOT recommended. Case 5 results in worse performance than using default **Basic Saturation Flow**. For Case 6, performance is similar to using the default **Basic Saturation Flow** but disabling Saturation Flow estimation by the program is bad practice.

The performance results of Case 1 seem realistic as this site operates at capacity in the AM peak and demand was probably measured at the stop line. Cases 2, 3 and 4 demonstrate that using the method of calibrating to recorded SCATS MF yields unrealistically optimistic performance for the intersection as a whole, partly because of the variability of SCATS MF with signal timings.

In the case study given here, the design and signal operations decisions for this intersection would be based on the performance measures in Cases 3 or 4 while the calibration of Saturation Flow to match the **Recorded SCATS MF** is carried out for Case 2. The results for Cases 3 and 4 are significantly more optimistic than those found when using the default **Basic Saturation Flow** in Case 1. However, no systematic performance surveys were carried out as part of this investigation.

Appendix B – Examples of Incongruous SCATS MF Values

Example 1 - Princes Hwy / Tooronga Rd, INT=2417

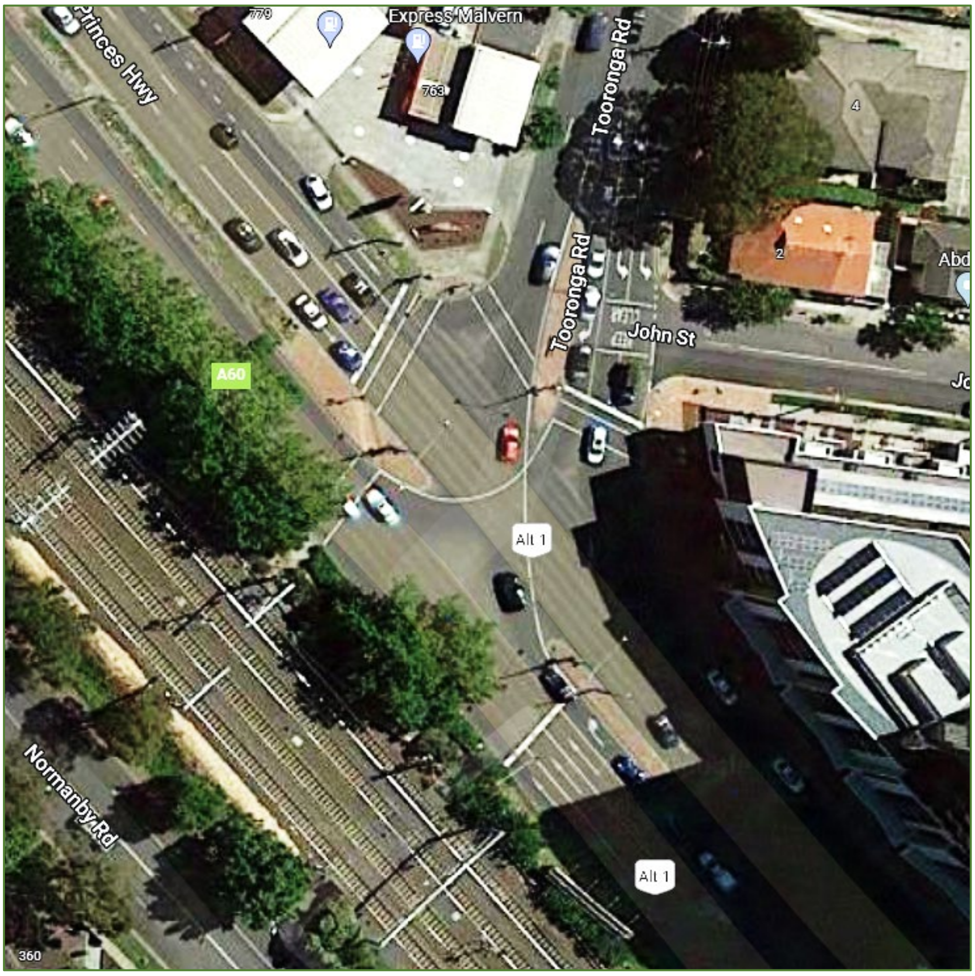

Figure B1 - Aerial photo of Princes Hwy / Tooronga Rd

NW approach:
SI2=2417,1!D#=1-4!
MF=1423,1614,1856,1946!NF=0,0,0,0!
KP=115,78,77,78!AV=3722,8545,10283,10077!

The MF of 1423 in Lane 1 does not represent full saturation. This lane is a short lane on the approach side and is unlikely to reach full capacity.

There is a large difference between MF for Lanes 2, 3 and 4.

The MF value of 1614 for Lane 2 could be explained by the short lane effect. If this is so, then calibrating Saturation Flow to this low value of SCATS MF would result in double counting the short lane effect.

The difference of 90 veh/h between Lanes 3 and 4 is difficult to explain, as both lanes have the same characteristics. If the intersection were operating fully at (or over) capacity, you would expect both lanes to be able to achieve the higher flow rate.

Example 2 - Princes Hwy / Grange Road, INT=2420

Figure B2 - Aerial Photo of Princes Hwy / Grange Road

SE approach:
SI263=2420A!D#=1-4!
MF=+1989*,1731,1756,1905!NF=0,0,0,0!
KP=62,61,77,43!AV=3265,6999,9848,10064!

Lane 1 does not experience fully saturated flow and does not meet the SCATS criteria for recording a valid MF value. The substituted value of 1989 veh/h is higher than the other lanes on this approach.

The values for Lanes 2, 3 and 4 on this approach are 1731, 1756 and 1905, respectively. This indicates a 10% difference between the recorded SCATS MF for Lanes 2 and 4 whereas any functional reasons why the Saturation Flow should be different for these lanes are not evident.

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