Australasian Transport Research Forum 2011 Proceedings
28 - 30 September 2011, Adelaide, Australia
Publication website: http://www.patrec.org/atrf.aspx

The Evolution of the SCATS and the Environment Study

Christian Chong-White[1], Gareth Millar [2], Fraser Johnson[1], Steven Shaw[1]

[1] Roads and Traffic Authority of New South Wales
Australian Technology Park, Locomotive Workshop, Suite 3120. 2 Locomotive Street, Eveleigh NSW 2015 Australia

[2] Azalient (Australia) Pty Ltd
Australian Technology Park, National Innovation Centre, Suite 145, 4 Cornwallis Street, Eveleigh NSW 2015 Australia

christian_chong-white@rtra.nsw.gov.au

Abstract

This paper explains the evolution of a running study titled 'SCATS and the Environment' (SatE) by the Roads and Traffic Authority of New South Wales (RTA) (NSW). SCATS is a comprehensive traffic management system that provides adaptive traffic control, amongst other functionality. The SatE study is tasked to rigorously demonstrate the transport, environmental and economic value that the SCATS installation provides to the people of NSW. We consider the evolution of the SatE study to have two forms: (1) methodological and (2) experimental. We use these forms to describe an ordered schedule of salient decision points that records the progress of the study. We explain the incrementally developed and refined experimental design that is specifically targeted to defensibly assess SCATS performance outcomes. This paper provides some insight for modelling practitioners on the appropriate experimental design of studies that investigate automated traffic control. The presentation puts on public record the details of the study process to support the publishing of the SatE traffic performance results in another paper.

1. Introduction

This paper explains the evolution of a running study titled 'SCATS and the Environment' (SatE) by the Roads and Traffic Authority of New South Wales (NSW) (RTA).

SCATS is an area wide traffic management system developed by the RTA. It controls the cycle time, green splits and offsets for signalised intersections and mid-block pedestrian crossings. With the inclusion of vehicle detectors, it can adaptively modify these values to optimise the operation to suit the prevailing traffic. Alternatively, it can manage intersections in fixed-time mode where it can change plans by time of day, day of week. It is designed to coordinate traffic signals for networks or for arterial roads. (RTA 2011a) SCATS is currently used in 42 countries and 142 cities around the world.

The RTA manages the majority of the motorways and arterial roads across NSW, including some ~3500 SCATS signal controlled sites.

The SatE study was first conceived to address an enquiry requesting that the RTA consider contributing to an official report for the 2009 United Nations Climate Change Conference in Copenhagen, Denmark (Ministry of Foreign Affairs Denmark 2011). The requested topic was for the RTA to share its expertise to inform the conference of the contribution that adaptive traffic control can provide to managing of carbon emissions that are generated from road vehicle activity.

The request prompted an internal discussion on the informational evidence that the RTA had readily available to substantiate the operational traffic performance outcomes that the

SCATS installation provides the NSW road users and stakeholders. These positive outcomes are intimately known by the RTA from practical experience operating the NSW road network. Some previous high level analysis of SCATS existed, e.g. Bastable 1980; Nguyen 1992. However, the RTA considered that available information – developed for other purpose and/or was historical – was not appropriate for the immediate, required purpose.

In response, it was determined that a dedicated study was required to demonstrate the environmental, transport and economic value that the operating SCATS installation provides to the people of NSW. For reasons to be explained in this paper, the RTA declined to present at the Copenhagen conference. However, the stimulus has been used to mandate the SatE project with the aim to arm the RTA with the appropriate evidence for internal and external purposes.

2. Study design

We consider the evolution of the SatE study to have two forms: (1) methodological and (2) experimental. We use these forms to describe an ordered schedule of salient decision points that records the evolutionary study process.

2.1 Methodological design

The SatE study was charged to rigorously demonstrate the transport, environmental and economic value that the operation of the SCATS installation provides to the people of NSW. This required that the results of the study be representative of the NSW SCATS installation.

2.1.1 How to reveal SCATS operational value?

A key question that faced the SatE project was how to determine an appropriate method to defensibly articulate 'SCATS operational value', i.e. "how can we show the value that SCATS operation is providing today?" This question drew much discussion by project stakeholders.

Initially, the project team considered having developed a fixed time plan that could be compared in scenario testing against SCATS. However, when this proposal was considered in detail it was realised the fixed time plan would be hypothetical and not practical because an operating fixed time system does not exist at this location. Moreover, that choosing an appropriate practical fixed time system for comparison would require a research project, in itself.

The project team eventually concluded (in the later stage of the study) to use the configured fallback mode of the SCATS installation as a valid 'contrary' traffic control policy for comparison to normal SCATS operation. The SCATS fallback mode is often configured to operate when there is a systems fault, e.g. communications break between the controller and regional computer. The fallback mode is a simplistic form of adaptive traffic control – compared to normal SCATS operation. The fallback mode can often have fixed time characteristics that are triggered by day and time of day – but also some level of local adaptive traffic control behaviour that responds in real-time to detector measurements. Different sites may have different fallback characteristics based on the local conditions and constraints, e.g. some sites have no fixed time plans and are only locally adaptive. The fallback mode including fixed time plans are maintained by RTA Network Operations.

This modelling choice to use the fallback mode as a contrary scenario means that normal SCATS operation was compared to an alternative, maintained and relied upon, traffic control policy. Moreover, this ensured that the SatE study produced immediate and tangible information value to RTA practice.

2.1.2 How to measure SCATS operational value?

Recent RTA investigations have indicated the difficulty of measuring traffic performance in the real world and defensibly attribute that performance to known changes in traffic signals policy (e.g. Geers et al 2010). A key issue is that the variability of traffic – including travel demand, network conditions, environmental conditions and road user behaviour, is much greater than the expected difference of the performance under test. This is more likely true for an adaptive traffic system, where performance improvements could be expected to be “on the margin”.

The issue of real-world traffic variability is further confounded by the difficulty in measuring road user experience. Typically road operators have a tenuous ability to measure the travel experience of road users across the road network and across time. The RTA is well armed in this case, with extensive use of inductive loop detectors – commonly located at the stop-lines of each approach lane at the majority of intersections in NSW. In addition, the RTA also has other road user measuring technology, including travel time measurement using electronic toll tags. However, even with competent instrumentation of the road network, e.g. loop detector coverage, and to a far lesser extent other techniques, it has proved a considerable challenge for the RTA to observe traffic at sufficient ‘depth’ to counter the underlying ongoing variability of traffic.

In the case of the SatE study, it was required to not only measure physical ‘road engineering’ metrics such as time gaps, occupancy, headway, travel time, but also measure the environmental emissions emanating from travelling vehicles. With the exception of select tunnels in NSW – that are not subject to SCATS traffic control and therefore not relevant to the SatE study – the RTA does not have access to widespread on-road measurements of vehicle emissions. The RTA does, however, have access to Australian vehicle emission test data derived from laboratory experiments.

The solution adopted in the SatE project was to use calibrated traffic simulation as an estimating surrogate to real world measurement. In traffic simulation the modeller often has the ability to use sophisticated instrumentation of road users within the virtual world. The traffic simulation Commuter (Azalient 2011) – which was used in the latter stage of the SatE study – provided, in addition to physical measures, the ability to measure the simulated emissions of individual vehicles at each simulation time step based on the current modelled vehicle characteristics.

The emission factors currently included in Commuter are based on a review and assessment of factors for Euro I and II vehicles given in TRL Database of Emission Factors, September 2001 (Barlow, Hickman and Boulter 2001). Future enhancements to the SatE study will look at incorporating more recent Australian vehicle emission factors derived from laboratory test data. The intention is to adopt RTA approved values when available.

Having adopted traffic simulation as the analysis technique for the SatE project it was then required to develop an appropriate experimental design to steer the modelling process and deliver results that were appropriate for the requirements of the study.

2.2 Experimental design

The focus and adopted analysis methodology of the SatE study required credible modelling of the operation of SCATS in traffic simulation. The RTA has previously developed a capability to address this need known as SCATSIM.

SCATSIM (RTA 2011b) enables operation of a real SCATS system within an accommodating traffic microsimulation model. Aimsun (TSS 2010), Commuter (Azalient 2011), Q-Paramics (Quadstone 2011), S-Paramics (SIAS Limited 2011) and VISSIM (PTV AG 2011) provide a SCATSIM interface as an alternative to their internal signal modelling capabilities. SCATSIM can be run at real-time or faster than real time. SCATS interfaces to the simulator to primarily facilitate the communication of simulated traffic signal states and detector actuations. (Chong-White, Millar and Johnson, 2010)

Adopting SCATSIM for the SatE study allowed the modellers to operate the SCATS installation – as configured in the real world – to an equivalent virtual road network that was constructed in traffic simulation. The SatE project has used the traffic simulation applications, Q-Paramics and Commuter, both with SCATSIM.

Operating the 'real' SCATS in simulation means that the SCATS operation should be authentic and therefore representative to the real world equivalent. However, this representativeness is only as good as the:

1. Quality that the traffic simulation model is representative of the real-world traffic problem; and the
2. Degree of artificial effects imposed on the modelled SCATS for the purposes of simulation.

Point 1 concerns the quality of all traffic simulation matters other than the traffic signal control that is provided by SCATS, but including the interface to SCATS. Key issues that concern point 2 include, the:

a. Edge effect of artificially 'starting' both SCATS and the network demand within the simulation, and the
b. Need to often artificially 'cut' out part of a SCATS installation to fit with the desired network scope of the model, e.g. a subset of the NSW SCATS installation as done for the SatE project.

(The issue of an appropriate experimental design of a SCATSIM study is discussed further in Chong-White, Millar and Johnson 2010.)

2.2.1 Model scenarios

As explained, the methodology adopted for the SatE study was to compare SCATS normal operation against fallback operation. Over the course of the SatE study this evaluation was undertaken by running a number of scenarios:

1. Masterlink scenario: That employed the SCATS Masterlink mode that demonstrated the full adaptive signal control capability of SCATS. In SCATS parlance, this mode implements both strategic control (across intersections and time) and tactical control (real-time local control). This mode was in use on the calibration day 25/11/2009 and is normally used in practice at the intersections that were modelled. (Chong-White, 2010a)
2. Fallback scenario: That employed the SCATS fallback facility that applied the 'fall back mode' configured in practice at the intersections that were modelled. SCATS falls back when a systems fault occurs, e.g. a loss of communication to the controllers located at the intersection site. (Chong-White, 2010a)
3. Flexilink scenario: That employed the SCATS Flexilink mode that demonstrated the enhanced fixed time signal control capability of SCATS that provides some adaptive traffic control, e.g. the skipping of non-demanded phases; this mode is (often) the 'fall back mode' configured in practice at the intersections that were modelled[1].

[1] This was true for all but one controller in the modelled area. The Manly Road / Spit Road intersection was configured to fallback to Isolated mode.

4. Isolated scenario: That employed the SCATS Isolated mode demonstrated the localised adaptive signal control capability of SCATS. In SCATS parlance, this mode implements only tactical control. This mode does not consider coordination between adjacent intersections and (simply put) extends the green display while vehicles are traversing the detectors up to a configured maximum time setting. This mode is also used as a fallback mode in specific cases.
5. Playback: That had the traffic signals configured in the model "play back" 15 minute averages of the traffic signal time and duration matching that observed on the 'real world' production SCATS system on the calibration day. The traffic signals in this scenario were not fully adaptive to the traffic state within the model. Accordingly, this scenario was useful to consider that the traffic signals are "held constant" – to the real world – and the other aspects of the model can be interpreted with this understanding. (Chong-White, 2010a).
6. Fixed time scenario: That used a fixed time plan that was 'manually optimised' (to some degree) by observing the simulation running and adjusting the signal settings to get effective queuing outcomes.

For reasons as discussed later in the paper, only the Masterlink scenario and the Fallback scenario of the SatE study were considered to be realistic alternative strategies that could be adopted by the RTA on the existing traffic control configuration.

3. Evolution of the project work flow

The SatE study has evolved through a number of stages each drawing from the findings of the previous stages and each stage using a different model. The work flow follows:

1. Pilot study (completed),
2. Main study – phase 1 (iteration 1) (completed); and
3. Main Study – phase 1 (iteration 2) (completed).

A Main study – phase 2, is currently underway.

3.1 Pilot study

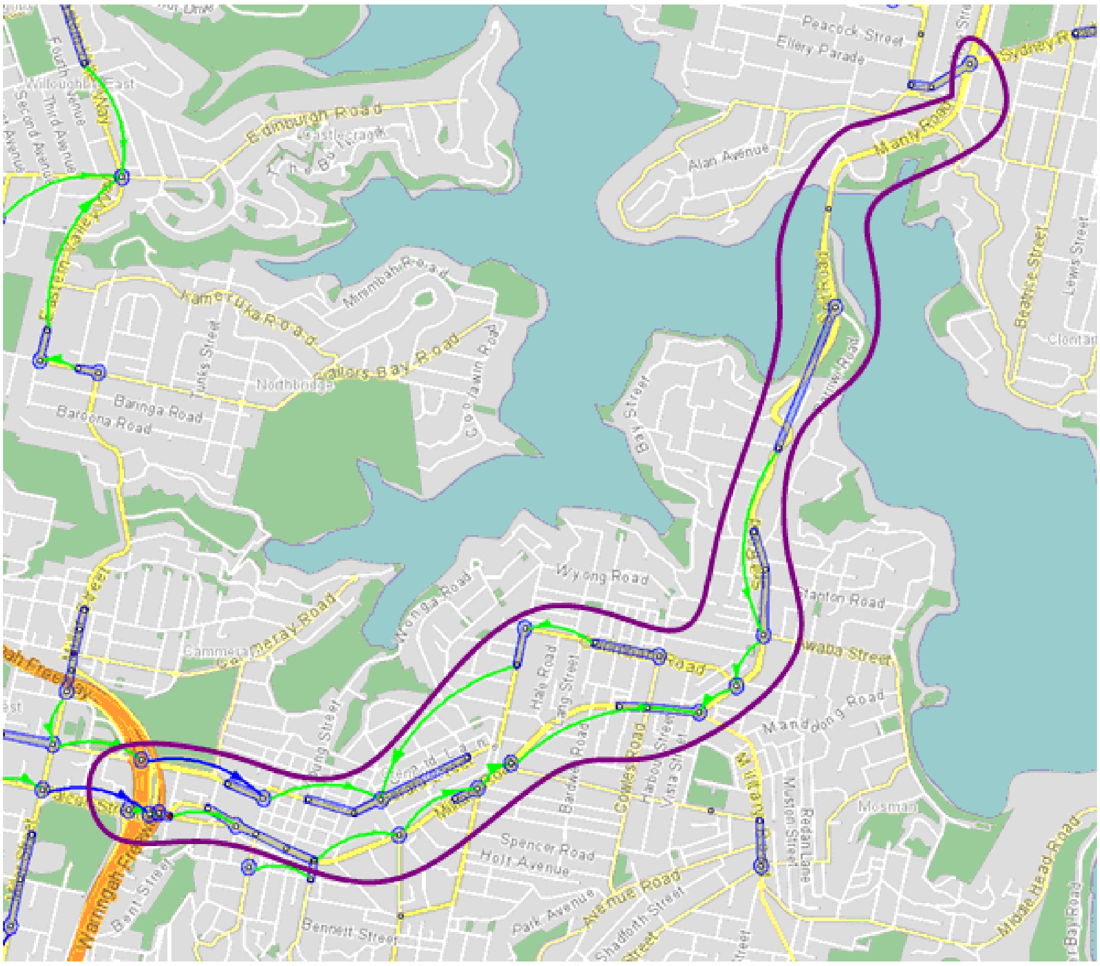
The SatE project commenced with what was eventually termed a SatE Pilot study. In the interest of efficiency, the Pilot study used an existing SCATSIM model of the Military Road / Spit Road / Manly Road (MRSR) corridor that had previously been commissioned by the RTA for other purpose. This decision was taken with some apprehension because the project modelling team was not intimately familiar with the design of the model or the quality of the real-world representativeness that was achieved with the model and with the SCATS configuration that operated within the model.

The choice of the MRSR corridor allowed the SatE study to capitalise on the pre-existing model; however, the choice of that part of the NSW network was chosen for other traffic management reasons. The MRSR corridor is a critical access route between the north east of Sydney to the north side of the Sydney Harbour Bridge that connects the North Shore to the central business district. The route is heavily saturated during the day on weekdays and often also on weekends. Due to the geography of Sydney Harbour and the adjoining waterways that surround the corridor, together with the density of housing and the high value of land, the options for the expansion of surface road capacity are limited. Accordingly, there is a strong need to maximise the value derived from road travel on the existing scarce road capacity. Effective traffic control is one of the mechanisms to contribute to this objective, given the constraints described.

The Pilot study model was developed using Quadstone Paramics Version 5.2. The model consisted of 34 SCATS controlled intersections from Sydney Road and Manly Road intersection in Seaforth in the north to the entrance of the Warringah Freeway at the intersection of Ernest St and Falcon Street in the west. The model is a network model with a dominant corridor and parallel and intersecting minor roads. The model was built as two separate demand scenarios: a morning peak 0600-1000 and an afternoon peak 1600-1800; however, due to time constraints only the morning peak was used in the Pilot Study.

Figure 1 shows the 34 intersection model highlighted as the network enclosed by the purple line. Each intersection is represented as a white circle; and each SCATS subsystem is represented as a blue region that encompasses the associated intersections. The critical intersection for each subsystem is shown within the blue circular region. SCATS links are represented as a green arrow for a currently married link (coordination adaptively enabled) and a blue arrow for a currently divorced link (coordination adaptively disabled).

Figure 1 Model area of the 34 intersection model from the Pilot study



The Pilot study model was used to analyse five scenarios:

1. Three scenarios each with different SCATS operating modes – Masterlink, Isolated and Flexilink;
2. Playback scenario; and
3. Fixed time scenario.

Each scenario used the same model but differed only by the applied traffic signal control strategy. Only the traffic control in the scenarios in point 1 was adaptive within the simulation (i.e. only those scenarios that operated SCATS within simulation); in contrast the other two scenarios were implemented using the traffic control logic within the simulation application itself (and not SCATS). Accordingly, only the scenarios in point 1 could be considered representative of expected SCATS outcomes for the relevant SCATS operating mode. Scenarios in points 2 and 3 were conducted for comparison purposes, i.e. to provide a sensibility check on the results of the scenarios in point 1.

For each scenario, demand variants were constructed: a calibrated 100% demand 'base' scenario and a 102% demand 'sensitivity' scenario (representing a 2% growth in base traffic conditions). Results from 10 runs of each scenario were compared.

On analysis, the Isolated scenario was rejected due to a specific controller configuration issue. The issue was that a particular intersection (Manly Road, Sydney Road intersection) was configured in production with a conditional phase that was triggered by a customised traffic signal routine. The routine allowed a right turn phase to be used only during specified times during the day (where the times were sign posted to inform road users). This routine existed in the scenarios that used Masterlink and Flexilink real world settings (modes normally used in SCATS NSW configuration), but was not configured in Isolated mode as this was not used in the SCATS configuration in production. The effect was the phase was not called in the model and modelled traffic using that phase suffered extreme delays that were unrealistic given the unrealistic traffic control that was applied.

The results from the Flexilink scenario were found to have a significantly larger number of vehicles remaining in the model at the end of the model period compared to the other scenarios. The implication was that the reporting of the traffic performance of 'completed trips'-only produced misleading values because the traffic performance of the vehicles that were delayed outside of the model were not reported. Simply put, comparing two scenarios that have different number of vehicles completing trips in the model means that it is not a valid comparison of total traffic performance metrics, i.e. "not apples to apples". Accordingly, the analysis was changed to also focus on incomplete trip data.

Only the Masterlink, Flexilink and Fixed Time scenarios were deemed appropriate for analysis. The results showed that in general the Masterlink scenario returned a higher average speed and lower numbers of stops than Fixed Time and Flexilink scenarios. However, in the second half of the simulation period (8:30 to 10:00 hrs) for the 100% demand, the Fixed Time scenario produced slightly higher average speeds. This finding was considered plausible given that the fixed time plans had been developed 'in sample' on the model itself; however, lessening this plausibility was the fact that the plans had been developed by visually tuning the model that – at face value – was considered not likely not to be a 'rigorous optimisation'.

In the 102% demand sensitivity scenario the average speed decreased with the Fixed Time scenario but remained around the same levels as for 100% demand with the Masterlink scenario. This consistency of traffic performance in the Masterlink scenario across the two different demand scenarios was reasoned to be attributed to the unique adaptive traffic control applied within the simulation.

To make analysis more problematic, error checking the numbers of incomplete trips revealed that the results were confounded by model reporting issues. It was determined by inspection that the simulation application – due to a plug-in issue – was incorrectly writing the number of incomplete trips. This issue made it difficult to interpret the results and understand the traffic performance implications of the alternative traffic control strategies.

At this point it was decided to close off and produce a debrief to project stakeholders on the status of the project, including the details of analysis and findings. In addition to the issues with the Pilot study as previously discussed, two other issues were of particular concern to the modellers:

1. It was known at the commencement of the project and grudgingly accepted due to time constraints at the time, that the experimental design that steered the original development of the model had allowed the modeller to apply customised configurations to SCATS. These configurations meant that the SCATS that was operated in simulation was configured (slightly) differently as compared to the configuration that was operated in the real-world. The modification was applied for the sole purposes of achieving the required SCATS outcomes – or more exactly, traffic signal outcomes – to match real world observations. In other words, "to tie down the adaptive traffic control in SCATS to achieve the require traffic signal outcomes in simulation". This methodology was considered deficient in the interest of achieving representative SCATS adaptive traffic signal operation, however, it is acknowledged that modelling is a process – that by definition – requires compromise. In the case of the SatE study – where the focus was the analysing the performance of SCATS – it was eventually decided that this aspect of the original experimental design (that was deemed acceptable for purpose of the original model) was inappropriate for the SatE case. This inappropriateness became obvious when attempting to analyse and understand the traffic signal and traffic performance results of the scenarios, and calibrate those outcomes to the targeted real world conditions.

   This conclusion was used to steer the experimental design in the next stage of the project.

2. There were some aspects of the modelling in the original model that was considered important by the SatE modeller given the aims of that study. These aspects, generally, concerned the road network environment and the representativeness of its effect on the SCATS adaptive traffic signal behaviour within the simulation. The concerns included the following matters:

   a. Pedestrian calls which have a significant effect on signal times;

   b. Vehicle/pedestrian interactions on crosswalks that can result in significant effects on vehicle travel on filtered turns;

   c. Analysis revealed the sensitivity of the compliance of the high occupancy vehicle lanes (called T3 lanes in NSW) on the mainline to queuing outcomes; and

   d. Public transport and the effect that stopping buses had on lane capacity and intersection capacity where stops were adjacent to intersections.

The debrief of the Pilot Study concluded that the described modelling and analysis issues raised question about the quality of the analysis results with respect to the SatE study. The modelling team recommended the results of the Pilot study were unusable for providing policy direction and/or marketing support. A responding list of recommendations for improvement to the study process was determined that included:

1. Reassess the model area, modelled period and pedestrian demand.

2. Sensibility check SCATS in simulation operation issues to ensure confidence of SCATS in simulation results.

3. Design a traffic performance and analysis framework to better report traffic performance outcomes.

4. Implement statistical modelling guidelines (Shteinman, Clarke, Millar, Chong-White & Johnson 2010) that concerned the experimental design of simulation studies – to improve the statistical rigour of the modelling applied in the SatE study.

5. Consider using alternative simulation software to better address points 2-4.
6. Consider using electronic tag information to provide travel times for model calibration rather than relying on only stop-line loop detector measurements as the only automated source of high-volume traffic measurement.
7. Consider using bus dwell information from GPS bus measurements taken from the RTA's Public Transport Information and Priority System (PTIPS) to more accurately specify bus dwells at bus stops.

These recommendations motivated aspects of the experimental design in the next stage of the SatE project.

3.2 Main study – phase 1 (iteration 1)

The second stage of the SatE study was termed the Main study – phase 1. In this section we will discuss the first iteration. The Main study drew from the experience and recommendations given from the Pilot study.

This stage saw the creation of a new model of the MRSR corridor that was focussed specifically on addressing the SatE study requirements. In particular – which was novel for the RTA – was the development of a traffic simulation model and associated experimental design that was focussed on the defensible investigation of SCATS operation and related traffic performance outcomes.

Chong-White, Millar and Johnson et al (2010) describes the experimental design of the Main study. Key novelties of that experimental design – that in part responded to the Pilot study recommendations – include:

1. Running of SCATS in simulation in an 'untouched' form equivalent to the SCATS configuration in the real-world, i.e. base case model developed to achieve SCATS in simulation outcomes that are representative to real world equivalent without 'corrupting' the SCATS configuration.
2. Sophisticated analysis of real-world SCATS results to understand location of critical detectors that control signal control outcomes that was subsequently used to steer the choice of the network scope to be modelled.
3. 24 hour model starting and ending at 0300 to minimise artificial edge effects of starting SCATS and to ensure full spectrum of traffic demand dynamics and transport outcomes are considered.
4. Detailed travel time calibration using electronic tag data (in-bound only).
5. Detailed bus modelling calibration using PTIPS GPS bus stop dwell data.
6. Comprehensive pedestrian crossing demand and calibration.
7. Detailed high occupancy lane (HOV / T3) calibration using RTA survey data.
8. Detailed reporting of transport economic outcomes from RTA Economic Analysis Manual (RTA 2009).
9. Provide ability to report outcomes at the travelling person level in addition to vehicle level.
10. Comprehensive reporting of simulated environmental outcomes and the sensibility checking of environmental results by RTA Environment Branch.

(Chong-White 2011)

In addition, following one of the Pilot study recommendations, the network scope of the model used in the Main study was reduced significantly from 34 SCATS controlled intersections in the Pilot study to 7 intersections. This also had the effect to change the model topology from a network model – with potential route choice, to a linear model – without route choice. The resulting Main study model was centred on a key intersection on the MRSR corridor at the Military Road / Spit Road intersection at Spit Junction. This dramatic simplification was undertaken to first work with a more manageable model to develop an appropriate experimental design with which to defensibly analyse the performance of SCATS, i.e. "learn to walk before you run". The intention – currently underway at the time of writing this paper – is to expand the model scope once that appropriate experimental design had been achieved.

The Main study uses the 24 hour period – from 0300 on the 25 November 2009 to 0300 26 November 2009 – as the calibration day. The choice of that day was made based on an analysis of the flow profiles across a spanning two week period. That two week period was chosen based on an absence of any reported non-normal incidents and for other traffic system reasons.

The choice of the scope of the model was subject to investigation to determine the implication to the SCATS configuration. The concern was to ensure that the integrity and representativeness of the operation of the SCATS installation was managed when cutting out a part of the SCATS installation for the artificial purposes of modelling. In practice, SCATS controls the vast majority of controlled intersections in the state of NSW; clearly, this cannot be modelled efficiently in a single model.

When using a subset of a SCATS installation there is a risk the cutting out invalidates SCATS dependencies that are a function of the configuration. Two examples of SCATS dependencies that are critical to consider when modelling with SCATSIM include:

1. SCATS linking that reflects configured relationships between intersections to provide coordination of signal scheduling between adjacent sites, e.g. to provide 'green waves', and the
2. Use of remote detectors located at upstream and/or downstream sites for signal control at another site.

The risk of not modelling a link is the potential loss of specific non-modelled influence on the SCATS traffic control decision-making within the simulation; this error results from the missing information. Note that when using SCATSIM, SCATS is identical and therefore operates as one expects in the real world; rather, the issue here is that the modelled SCATS is potentially not exposed to the same information as expected, and therefore makes different responding decisions. (Chong-White, Millar and Johnson 2010). The same is true for detectors that are missing from a model. If SCATS is not exposed to detector inputs that it would otherwise expect in the real world equivalent, then SCATS will 'see the (virtual) world differently' and respond differently in simulation.

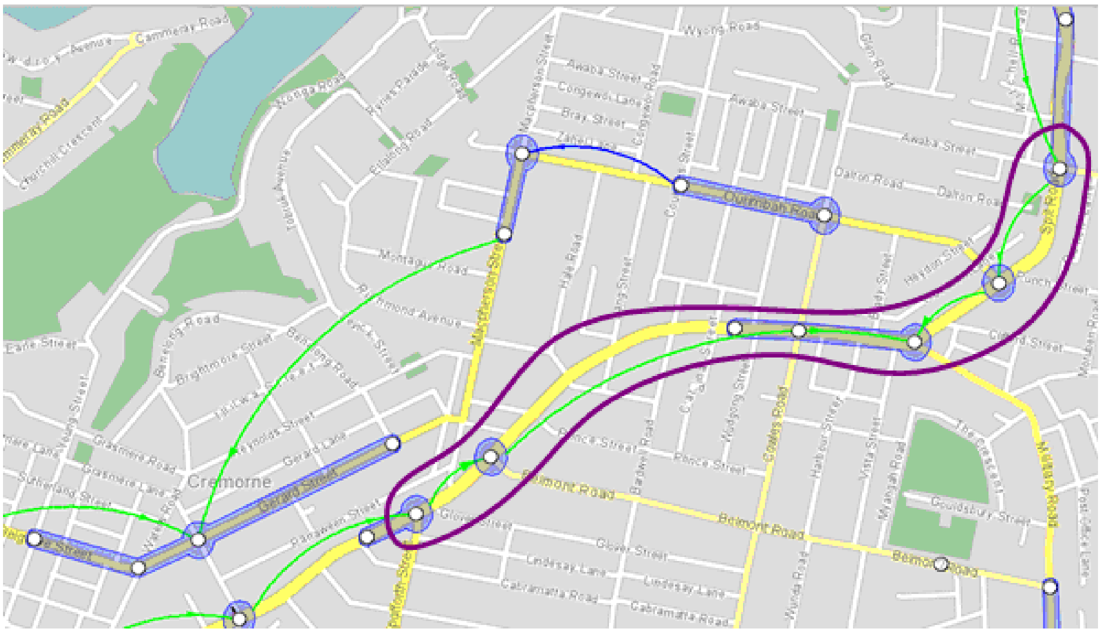
In the case of the 7 intersection model the choice of the network scope was aimed to avoid 'breaking' SCATS links that are configured to allow SCATS to adaptively coordinate the subsystems pair that shares the link; rather, the edge of the network was positioned to 'break' within subsystems (where a subsystem is a controlled set of intersections that are controlled with a same cycle time). Moreover, the affected subsystems were cut in a manner to ensure the critical intersection of that subsystem was retained within the model.

Figure 2 shows the extent of the 7 intersection model highlighted by the purple line; refer to the explanation for Figure 1 to understand the visualised SCATS objects. The purple line demonstrates the careful selection of the model area where the 'cuts' through SCATS dependencies were chosen to occur within subsystems – while retaining the critical intersection of each cut subsystem, and not across the links between subsystems.

The location of the edges of the model were also chosen to avoid any direct dependency of the signal control within the model to detectors that were outside the scope of the model.

However, even though direct dependency to detectors was avoided, the linking relationships that join the subsystems on the periphery meant detectors outside the model scope could influence cycle time within the model area. This indirect affect was analysed in detail for the calibration day to understand the controlling detectors on the greater MRSR corridor understand the implications to the choice of the model area. (Refer to Chong-White et al 2010 for more detail.)

Figure 2: Model area of the 7 intersection model from the Main study – phase 1



In the Main study a different traffic simulation application – Commuter (Azalient 2011) – was adopted to that used in the Pilot study – Q-Paramics (Quadstone 2011). The change was due to a number of advantages but the immediate stimulus was the ability of Commuter to allow the modeller to conduct the modelling process in a statistically rigorous and accountable manner. This characteristic was important to the project team to capitalise on a parallel RTA project – now completed – that was developing a statistical framework to guide traffic simulation studies (Shteinman et al 2010). That guidance is intended to strengthen the statistical rigour that underpins the experimental design and implementation of traffic modelling studies. The modellers of the SatE project have drawn from that work to increase the defensibility of the SatE study results.

3.2.1 Subject matter expert advice

At an advanced stage during the Main study the modelling team met with a number relevant subject matter experts (SME) to gain advice on aspects of the experimental design to ensure it met appropriate RTA practice and was therefore considered representative of RTA practice.

The first SME meetings (Davies, Dowdell, Millar, Chong-White & Shaw 2010) was with the RTA Environment Branch to have that team analyse and sensibility check the Commuter vehicles emissions model. The Environment Branch uncovered a number of inconsistencies in the entered emission factors in Commuter that were subsequently corrected by Azalient. The Environment Branch suggested that the emissions factors used in the Azalient Commuter software may not be representative of Australian conditions as they are based on European vehicle test data (for Euro I and II vehicles) and do not include newer Euro III vehicles or older/pre Euro vehicles which are also represented in the Australian fleet. The Environment Branch undertook a comparison of Azalient Commuter predicted emissions against emissions predicted using emission factors from published studies and other accepted sources. This comparison indicated that modelled emissions estimates may be conservative. The representation of acceleration and deceleration effects in the adopted emissions model was found to require some improvements in the next stage of the project. (Davies and Dowdell 2011)

A second SME meeting was held with the SCATS development team (Bagde, McCallum, Rubbi & Chong-White 2010) to gain their advice and approval on the experimental design of the SatE study. The team suggested using the alarms that are reported by SCATS as a means of identifying experimental design errors that are affecting the operation of SCATS within the model.

A third SME meeting was with RTA Network Operations (NetOps) whom are the team charged to manage the NSW SCATS installation (Campara, Dixon, Morson & Chong-White 2010). In particular, the modelling team wanted NetOps to review the design of the scenarios. NetOps (Campara 2011) brought to the modellers' attention that not all intersection controllers in the 7 intersection model had the fallback configured for Flexilink mode. To this time, the Main study was following on from the Pilot study assuming that the Flexilink scenario was the appropriate fallback for all modelled intersections. However, at the time of the calibration day the Flexilink plans for the Military Road / Spit Road intersection were not maintained and therefore not currently used in the controller. Rather, this controller was configured to use Isolated mode as a fallback mode, and not the often-used Flexilink mode. Accordingly, it was deemed that the results of the Flexilink scenario could not be considered representative of production practice because the traffic control behaviour of that controller could not be relied on. As a result the Flexilink and Isolated scenarios were deemed unrepresentative to production practice and discontinued. (This realisation also served to diminish the validity of the Flexilink scenario that was previously conducted in the Pilot study.)

A Fallback scenario was constructed that aligned the fallback settings of each controller to match that configured and expected to operate in the production system. (The Fallback scenario was used in the next iteration discussed in the next subsection.)

The critical general point from NetOps' advice was that attempting to model SCATS in a representative manner, but with a non-realistic configuration, is a challenging exercise. Moreover, that it is easier and more comforting to use the SCATS real-world configuration in an unchanged manner to the most-honest degree possible. Any deviation from practice requires careful application and local SCATS installation expertise.

The first iteration of the Main study produced: 5 runs, 3 runs and 5 runs for the three usable scenarios: Masterlink, Fallback and Playback, respectively. This few number of runs per scenario was considered insufficient based on the advice contained in the guidelines (Shteinman, Clarke, Chong-White, Millar & Johnson 2010).

The preliminary results from the Main study – phase 1 (iteration 1) indicated that Masterlink scenario produced 45% improvement in total travel time, a 29% reduction in stops and a 17% reduction in estimated CO_2 emissions over the Fallback scenario. Compared to the Playback scenario, Masterlink produced a 28% improvement in total travel time, 1% improvement in stops and a 1% reduction in estimated CO_2 emissions. These differences were found to be statistically significant at 95% confidence. However, as stated, these results were preliminary as it was considered that 3 or 5 runs was insufficient and the modelling process had yet to provide the modellers with enough experience or results to gain confidence in the robustness of the model.

However, some confidence in the experimental method was drawn from the comparative findings between: (1) the Masterlink scenario (that operated SCATS within the simulation), and (2) the Playback scenario (that modelled a fixed time plan based on SCATS signal times taken from those actuated in production on the calibration day). The Masterlink scenario allowed SCATS to adapt dynamically to variations of traffic flow within the model and “gap out” phases to shorten green times; this phenomenon could not happen in Playback scenario that had no adaptive traffic control. It was therefore considered plausible by the modellers that this ‘gapping’ and adaptive traffic control behaviour – if working effectively – would increase the effectiveness of green signals to the variations in demand in the model. This strategy should free up that green time for better use to influence a reduction in total travel time of road users; however, this strategy (at face value) should not increase stops but may not necessarily significantly decrease stops.

A traffic performance reporting issue that was identified by the project team in a parallel project (Shteinman et al 2010) was the ignoring of delays suffered by vehicles waiting to load onto the model (due to queuing effects that extending to the edge of the model). This phenomenon is often unavoidable in complex road networks because queues are commonplace and a boundary for the model area cannot always completely negotiate around all the expected queues. This phenomenon is a characteristic of the MRSR corridor. The phenomenon becomes more acute for contrary scenarios that are often testing more extreme congested conditions, e.g. future year with traffic demand growth; or in the SatE case, an inferior control policy, e.g. Fallback scenario, that produces greater queuing outcomes. The synopsis is that the analysis technique must be able to accommodate this phenomenon – particularly when attempting to compare the traffic performance between scenarios where this phenomenon is different between scenarios, and potentially also, different across the duration of each scenario. The solution (Shteinman et al 2010) was to use an ‘adjusted total travel time’ (or total VHT – vehicle hours travelled) that represented the sum of the total travel times of all vehicles plus the ‘waiting time’ at the edge of the network. The ‘waiting time’ is the difference between when a vehicle is scheduled to load into the model network at the origin of its trip, and the time it actually loads, i.e. due to delay effects from queues extending to the edge of the network. This solution only mitigated the traffic performance reporting for performance analyses of travel time and delay; it did not offer a remedy for other performance metrics, e.g. stops, or emissions. However, for travel time analysis, the solution provided clarity to the investigation of SCATS outcomes between scenarios where disparate ‘waiting time’ outcomes are reported. The solution was integrated within the traffic performance reporting of the traffic simulation Commuter and folded into the analysis technique in the next iteration of the Main Study – phase 1.

3.2 Main study – phase 1 (iteration 2)

The second iteration of the Main study saw a refinement of the experimental design and improvements to the model including the running of the appropriate Fallback scenario. The refinements to the experimental design (other than the Fallback scenario) were primarily aimed to reduce the impact – on the traffic performance results – of modelling issues that created unrealistic traffic behaviour such as ‘stuck vehicles’.

The development of a traffic simulation model is similar to a conventional software development lifecycle process. Similar to software, the development of a traffic simulation model requires design, coding and testing. The process of producing a robust traffic simulation model – that minimises erroneous model behaviour, e.g. artificial ‘stuck’ modelled vehicles that cannot move for an unrealistic period of time – is a similar want to the removal of ‘bugs’ in conventional software development. Producing bug-free code is an aim that in complex code, like traffic simulation models, is never perfectly achieved in practice. The challenge for modelling is accommodating this issue when analysing the results to mitigate the chance of unreasonable results from distorting interpretations of the overall results.

A technique was developed to identify suspect errant runs by identifying individual vehicles that caused time-localised delays at a scale that were unrealistic. Runs with such behaviour were removed from analysis. This technique allowed erroneous runs to be screened. This allowed appropriate runs to be confidently identified and used for analysis at an earlier stage of the model development process than was otherwise possible.

The second iteration of the Main study returned two scenarios: Masterlink scenario and Fallback scenario, each with ~30 completed runs (however, not all runs have been deemed usable for analysis due to simulation issues). This greater number of runs provided more clarity on the distribution of results and allowed an analysis of the normality of the distribution, e.g. distribution of total travel time across all runs within a scenario. The statistical guidelines (Shteinman et al 2010) had advised on 30 as a minimum number of runs (based on the central limit theorem) and to apply tests of normality as a check on integrity of the model.

Refer to Chong-White, Millar, Johnson and Shaw (2011) for results of the SatE Main Study – Phase 1 (iteration 2).

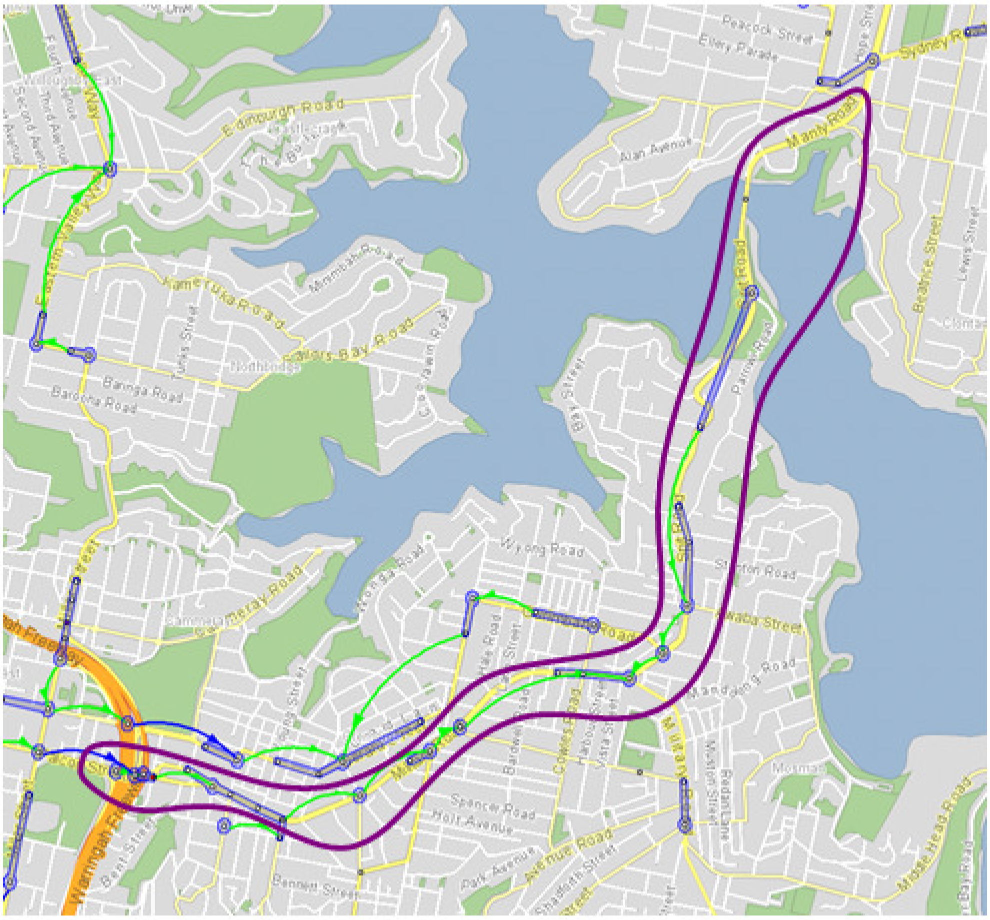
3.3 Main study – phase 2

The Main study – phase 2 is currently underway. The 7 intersection model used in the SatE Main study – phase 1 has been expanded to 21 intersections from Spit Bridge to Falcon Street. This is almost the mainline length of the model used in the Pilot study. However, for reasons of simplicity the phase 2 model is a corridor model without route choice (this aligns with the similar characteristic of the phase 1 model). The phase 2 model duration remains 24 hour from 0300 to 0300.

Figure 3 visualises the 21 intersection model highlighted as the network enclosed by the purple line; refer to the explanation for Figure 1 to understand the visualised SCATS objects. The Spit Bridge to the north provides a 'fire break' where there are no configured SCATS dependencies. The choice of the model edge on the north side was chose to capitalise on this phenomenon to avoid the need for breaking a dependency. This strategy was not possible on the west side of the model at the Warringah Freeway exit.

The reporting of the phase 2 results is intended for a future paper when that stage is completed.

Figure 3: Model area of the 21 intersection model from the Main study – phase 2



4. Conclusion

This paper has explained the evolution of a running SatE study by the RTA that is tasked to rigorously demonstrate the transport, environmental and economic value that the SCATS installation provides to the people of NSW.

The evolution of the study was considered in two forms: (1) methodological and (2) experimental, to describe an ordered schedule of salient decision points that records the progress of the study.

We explained the incrementally developed and refined experimental design that was specifically targeted to defensibly assess SCATS performance outcomes.

The paper provides some insight for modelling practitioners on the appropriate experimental design of studies that investigate automated traffic control.

The presentation puts on public record the details of the study process that underpins the SatE Study to support the publishing of the traffic performance results in another paper.

References

Azalient (2011) *Commuter*, (website), Azalient (Australia) Pty, Australia.

Bastable, A J (1980) The economic and social impact of dynamic signal co-ordination in Sydney, *ARRB Proceedings*, Volume 10, Part 4, Australia.

Chong-White, C (2010a) Preliminary results from SCATS and the environment (SatE) main study – stage 1, *RTA Memo*, (unpublished), version 21 December 2010, Roads and Traffic Authority of New South Wales, Australia.

Chong-White, C Millar, G and Johnson, F (2010) Introduction to modeling experimental design when operating SCATS within simulation, *Proceedings from the 17th ITS World Congress*, Korea.

Chong-White, C (2011) External SCATS and the environment project promotion, *RTA Memo*, (unpublished), version 20 January 2011, Roads and Traffic Authority of New South Wales, Australia.

Chong-White, C Millar, G Johnson, F and Shaw, S (2011b) The SCATS and the environment study: introduction and preliminary results, (to be published*), Papers of the 34th Australasian Transport Research Forum*, Adelaide, Australia.

Bagde, K McCallum, K Rubbi, N & Chong-White, C (2010), Brief and advice WRT SatE project, *RTA meeting*, 10th December 2010, Roads and Traffic Authority of New South Wales, Australia.

Barlow, Hickman and Boulter (2001), *Euro II TRL Database of Emission Factors*, September 2001, United Kingdom.

Campara, H (2011), Subject: RE: Conference paper for you information authorisation of NetOps aspects, RTA email, Roads and Traffic Authority of New South Wales, Australia.

Campara, H Dixon, A Morson E & Chong-White, C (2010), Brief and advice WRT SatE project, *RTA meeting*, 16th December 2010, Roads and Traffic Authority of New South Wales, Australia.

Davies, J and Dowdell, B (2011), Environment Branch Response on emission modelling for SCATS and the Environment project, *RTA Memo*, Roads and Traffic Authority of New South Wales, Australia.

Davies, J Dowdell, B Millar, G Chong-White C & Shaw S (2010), SCATS and the Environment Project Update, *RTA meeting*, 1st December 2010, Roads and Traffic Authority of New South Wales, Australia.

Geers, G Tyler, P Chong-White, C and Johnson, F (2010) Roundabout metering: simulation and reality, *Proceedings from the 17th ITS World Congress*, Korea.

Quadstone Paramics Ltd. (2011), *Quadstone Paramics*, (website), Quadstone Paramics Ltd.

Millar, G and Chong-White, C (2010) *SCATS and the environment: Pilot study: Final report*, (unpublished), Azalient (Australia), (for) Roads and Traffic Authority of New South Wales, Australia.

Nguyen, V N (1992) SCATS traffic control and air pollution, *Technical report*, Version: RTA/TCC/NN.9201, Roads and Traffic Authority of New South Wales, Australia.

RTA (2009) Economic parameters for 2009, *RTA Economic analysis manual*, Version 2, Roads and Traffic Authority of New South Wales, Australia.

RTA (2011a) *SCATS*, (website), Roads and Traffic Authority of New South Wales, Australia.

RTA (2011b) *Simulation software - SCATSIM*, (website), Roads and Traffic Authority of New South Wales, Australia.

RTA (2011c) *Products: SCATS*, (website), Roads and Traffic Authority of New South Wales, Australia.

PTV AG (2011), *VISSIM – Multi-modal traffic flow modeling*, (Website), Germany.

SAIS Limited (2011) Paramics microsimulation, (Website), United Kingdom.

Shteinman, D Clarke, S Chong-White, C Millar, G and Johnson, F (2010) Towards a statistical framework to guide traffic simulation studies, In proceedings *17th ITS World Congress*, Korea.

TSS (2010), *Aimsun 6 The integrated transport modelling software*, (website), TSS Transport Simulation Systems, Spain.