Microsimulation Evaluation of the Benefits of SCATS Co-ordinated Traffic Control Signals

Abstract

The development of micro-simulation traffic modeling software over the last decade has greatly contributed to the traffic engineer's tools available for analyzing complex traffic conditions and evaluating traffic management solutions. This paper reports on just one application, the evaluation of an area wide traffic control system using fixed time versus co-ordinated adaptive timing strategy for traffic signals. The SCATS (Sydney Co-ordinated Adaptive Traffic System) software is developed by the Roads and Traffic Authority (RTA) of New South Wales, Australia and has recently been adapted to communicate with vehicle-based simulation software. SCATS is not only used in Australia but throughout the world including USA, Mexico, and Asia. The traffic simulation model replaces the vehicles in the real world and transmits detector actuation messages SCATS central computer. These messages (detector "on", detector "off") are passed to the WinTraff software which emulates the personality logic of the local signal controller. After WinTraff has pre-processed the detector messages it passes data (traffic flow, non-occupancy etc.) to the SCATS simulation version. This version is the same as the real world SCATS except it runs faster than real time and has some house keeping processes. The combined software of WinTraff and SCATS in simulation is referred to as SCATSIM. Enabling SCATS to interface with micro-simulation models opens up a whole new range of possibilities in system optimization and evaluation, ITS application testing, and so on. The results reported in this paper demonstrate significant traffic benefits gained from co-ordinated adaptive strategies.

Introduction

This paper presents performance measures for micro simulation traffic models coded for fixed time signals and compares those to the same models communicating with SCATS (Lowrie 1992) (Sydney Co-ordinated Adaptive Traffic System) adaptive signal control.
The SCATS software is developed by the Roads and Traffic Authority (RTA) of New South Wales, Australia. It has been adapted to communicate with simulation software where the traffic simulation replaces the vehicles in the real world and transmits detector actuation messages. The messages (detector "on", detector "off") are passed to the WinTraff software that emulates the personality logic of the local signal controller. After WinTraff has pre-processed the detector messages it passes data (traffic flow, non-occupancy etc.) to the SCATS simulation version. SCATS then sends any phase change data to WinTraff which in turn updates the signal group colors in the model.

The SCATS simulation version is the same as the real world SCATS except it runs faster than real time and does not have the entire house keeping processes. The combined software of WinTraff and SCATS in simulation is referred to as SCATSIM.

This advancement significantly improves the simulation modeling process. Prior to this, most simulation models were required to be coded using fix time plans either to match static time of day signal control systems or as a proxy to adaptive signal control.

Enabling SCATS to interface with micro simulation models opens up a whole new range of possibilities in system optimization and evaluation, ITS application testing, and so on.

This paper reports on just one application, the evaluation of a traffic control system using fixed time, isolated vehicle actuated, and co-ordinated adaptive timing strategy. The results demonstrate significant traffic benefits gained from the co-ordinated adaptive strategies that SCATS delivers.

SCATS and SCATSIM

SCATS is an area traffic signal control system that adjusts signal timing in response to variations in traffic demand and system capacity.

Inductive loops are used to provide reliable measurement of space between vehicles (traffic demand). As vehicles travel over a detector the flow and occupancy are collected at the local roadside controller. After processing, the data is sent to the regional computer and used to calculate the SCATS “degree of saturation”.

In SCATS the controllers at each intersection can have three main modes of operation, namely:

- Masterlink Mode – under control of the SCATS regional computer
- Flexilink Mode – cable-less or synchronous linking (quasi co-ordination)
- Isolated Mode – independent vehicle actuated (VA) or fixed-time operation

The first two modes, Masterlink and Flexilink, give coordination between intersections in a defined area (sub-systems within a region). In Masterlink the phase sequence and maximum duration of each phase is determined by the traffic adaptive algorithms in the regional computer. With Flexilink predefined plans (current linking plans) are used to set the signal offsets, phase sequence, and maximum duration of each phase. The plans and schedules for Flexilink operation are held in the local controller although copies of these are also stored in the regional computer. If communications between the local and regional controllers fail, Flexilink may be used as a fall back operation from Masterlink.

In Isolated mode each intersection acts independently (uncoordinated) under vehicle actuation (VA) with time settings parameters specified in the local controller.

Masterlink and Flexilink can therefore be said to control the cycle time, the phase split and offsets between signalized intersections while isolated operation controls cycle time and phase split only.

SCATSIM is a package of software which emulates the local controller logic (WinTraff software) and runs SCATS software faster than real time (SCATS in simulation). As shown in Figure 1, WinTraff runs at the centre of communications between the traffic simulator software and the SCATS in simulation software. It carries out four main tasks:

- receives detector messages from the simulator
- emulates controllers and sends volume, non-occupancy etc. to SCATS
- receives phase changes from SCATS
- sends signal group colors to the simulator.

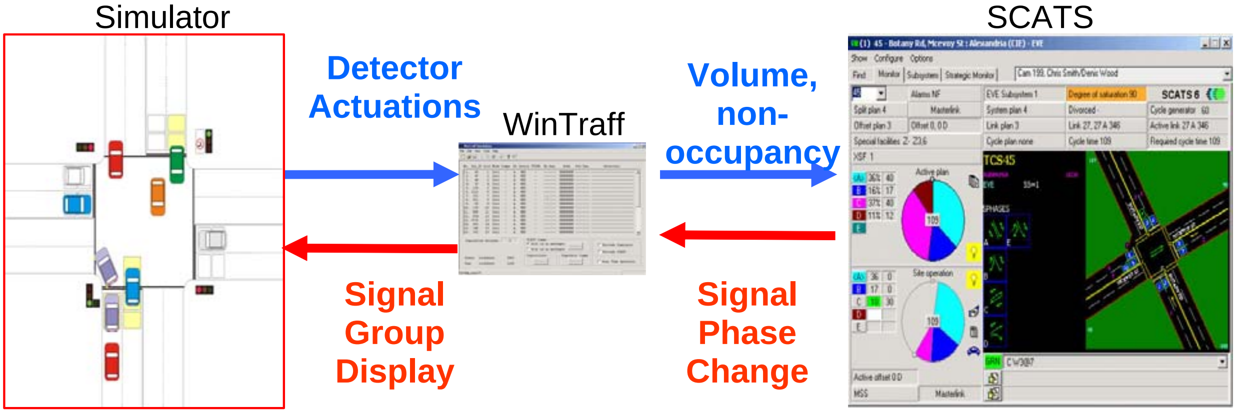

Figure 1 – SCATSIM Topology

Traffic Simulator

The accuracy of the simulator to SCATSIM process depends on how realistic the traffic simulator replicates the real world. In addition to sending and receiving messages the simulator needs to be able to model:

1. The behaviour of individual vehicles.
2. Detector actuations for individual lanes with a resolution of at least 20 milli-seconds (as provided by real SCATS controllers).
3. Traffic road rules such as filtered movements.
4. Common SCATS configurations e.g. single controller operating for multiple intersections.
5. Special conditions e.g. bus priority signal groups where there may be lane specific signal groups.
6. Interaction of pedestrians on the capacity of right and left turn vehicular movements.

QParamics (Quadstone), SParamics (SiAS), AIMSUN and Vissim are all undergoing continuing development with the SCATSIM interface to achieve the modeling as summarized above. In QParamics, the Application Programming Interface (API) was used to develop a plug-in that establishes communications to WinTraff and maps simulation detectors, intersections, movements, and signal groups to their equivalents in the SCATS system.

The authors considered QParamics (Quadstone 2003a) sufficiently developed to adequately model all six conditions listed above, and along with its API (Quadstone 2003b) feature, this software was selected for the evaluation and performance measurement testing.

The API consideration was important as it allowed development of a plug-in to capture performance data (delay and stops) to evaluate various modes of operation of the signals.

Simulation Test Model

Study Area

A small study area in Sydney (Australia) was selected, part of South Sydney metropolitan region. It consisted of a north-south route along Bourke Street with 6 signal controlled intersections (refer to Figure 2). This corridor model was chosen so that complications due to model route choice could be ignored (only one possible route between each origin and destination pair) and so the coding of the origin/destination (OD) demand could be simplified.

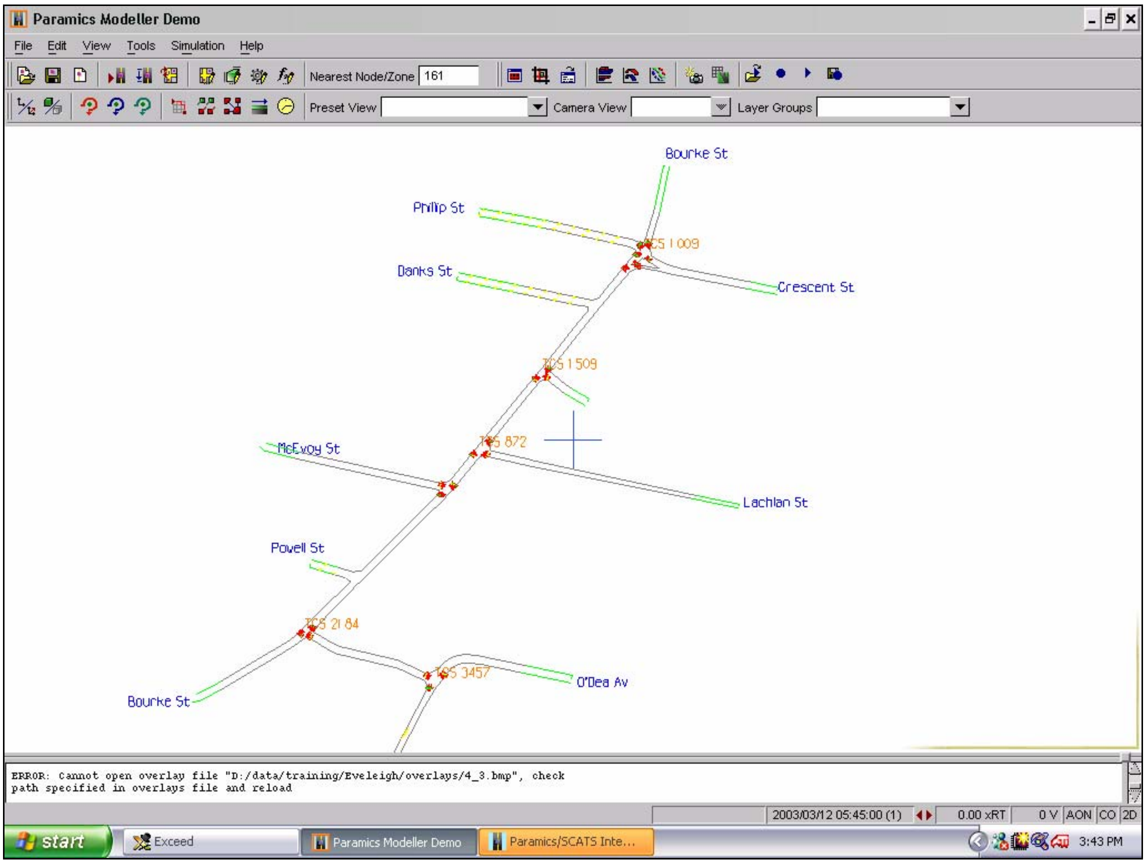

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Figure 2 – Test Network – Bourke Street, South Sydney, Australia

Traffic count data and signal timing data were collected for a weekday period from 5:45am to 10.15 am and these, together with local knowledge of trip patterns, were used to build the OD demand matrices. The profile of demand over this morning period and percentage splits by vehicle types, was taken from a manual classified count in the local area. The final origin/destination demand matrices were validated against independent count data.

Signal Control Operation

For the SCATS evaluation assessment, three signal control strategies were tested;

1. Fixed Time operation (coded as Paramics fixed time signals)
   - all signals run a common cycle time
   - offsets between intersections fixed
   - phase times fixed
2. SCATS isolated vehicle actuation (VA) mode (activated by local controller logic)
   - Each intersection operating independently under VA
   - Cycle time, phase plans and times governed by SCATS WinTraff controller
3. SCATS Masterlink mode (for 3 of 6 intersections)
   - Cycle time, phase plans and offsets controlled by SCATS

For fixed time operation, cycle times and phase splits were observed for the real world system between 8am to 9am. These times were then averaged and adjusted so that all six signals were coded to operate in QParamics with the same cycle time. Offset times between intersections were then manually adjusted until queuing in the simulation model was visually reduced. This was a qualitative assessment only and taken for a single seed value model run.

In most simulation models, vehicles are randomly generated in a pattern determined by a "seed" value. Using the same seed value enables repeatability of model runs. The use of a number of seed values enables different patterns of vehicle generation which attempts to reflect the random nature of real world traffic flow.

SCATSIM Setup

To model the SCATS operation modes, three set up stages were required:

1. Code Paramics detectors and mapping files to match SCATS real world detectors and signal groups.
2. Configure WinTraff to read the real personality logic for each intersection local signal controller.
3. Load the SCATS region and related subsystems configuration logic into the simulation version of SCATS.

For uncoordinated signal control (Isolated VA Mode) the WinTraff part of the SCATSIM software, communicates directly with the Paramics simulator. The connection to SCATS Region Manager in simulation is not required for isolated operation.

To enable signal coordination (Masterlink mode) the connections to SCATS in simulation are also required. Therefore the full communications between Paramics and SCATSIM (WinTraff plus SCATS) were enabled, as shown schematically in Figure 3 below.

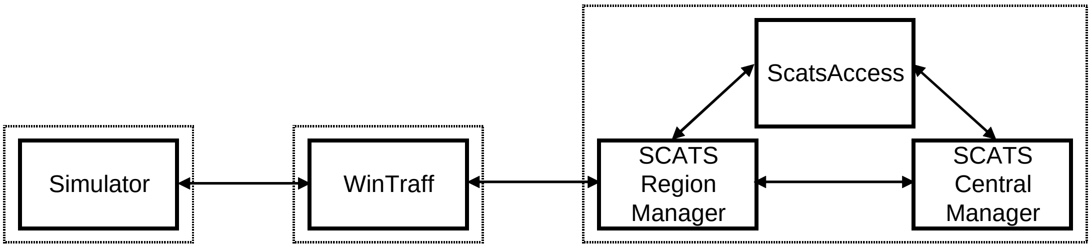


Figure 3 – Paramics and SCATSIM Communication Flow

It should be noted that the model study area had one shortcoming that diluted the impact of SCATS Masterlink control.

In the real world system, SCATS has been configured so the intersections at Bourke/Lachlan Streets, Bourke/McEvoy Streets and Bourke/Potter Streets are linked in a subsystem. The three remaining intersections in the modeled area either link to intersections not included in this model or operate in Isolated VA or Flexilink modes.

For this assessment, the mode of operation for the three intersections of Bourke/Philip, Bourke/O'Dea and O'Dea/Johnson Streets was defined to be Isolated VA.
Therefore, the model area was not entirely in Masterlink mode.

Evaluation Framework for Simulation Models

Traditionally, results from macroscopic traffic models are reported as averages for a given time period (e.g. flow in vehicles per hour) where all vehicles are assumed to travel in a homogenous manner.

Simulation models on the other hand produce vehicle by vehicle results which are more complex to report and understand. For the purposes of this study an evaluation framework was designed to analyze the overall system in an attempt to have a better understanding of all traffic.

As an example, consider a simulation model where the traffic demand is low, there is no congestion on the network and the traffic is controlled by signalized intersections (run A). Assume flow in the model over a 15 minute period shows that 1,000 vehicles complete their trips from origin to destination in an average time of 2 minutes per vehicle. The same model is run again but this time with the signal settings changed so that flow on the side roads receive less green time than the major roads (run B). It is possible that after 15 minutes run B shows less than 1,000 trips have completed their journey (due to congestion) but the average of these "completed" journeys remains 2 minutes per vehicle.

If run A and run B were compared only on the average travel time results of the vehicles that completed their trips, then both models would be reported as having the same outcome. This is clearly misleading.

In the above example the comparison ignores other traffic such as the vehicles that remain in the system and also importantly statistics for vehicles that would not load onto the network or are delayed due to congestion at the zone loading areas. To give a full picture of the operation of each model run it is therefore very important to report results for all trips from the demand matrix. These trips can be thought of in two classifications:

a) completed trips – vehicles that travel from their origin and arrive at their destination during the analysis period (this can include an element for time delayed before entering onto the model area)
b) incomplete trips – vehicles that load onto the network and travel part way to their destination but remain in the system at the end of the analysis period. The statistics include an estimate of time and distance to complete their journey (as with item (a), can include an element for time delayed before entering the model are).

The standard output from most simulation software will report traffic statistics such as travel time, for complete and for the part of incomplete trips so far completed. Usually this is done by recording the time that a vehicle loads onto the network, the time (and distance) when complete or the time (and current position) for the partially complete trips. However, no measure (or estimates) are provided for trips released which cannot start their journey due to congestion at the entry point of the model or estimates for incomplete trips to finish.
In addition, it is possible that completed/incomplete trips may have been delayed before loading onto the system (i.e. started as an unreleased trip which after a time managed to load as gaps became available on the network).

One way to report these statistics for each OD pair would be to record the attempted time of release, the actual time when the vehicle loaded, the time when the trip finished and the current time. By subtracting these times it would be possible to provide a more complete picture of the vehicle travel times and delays. Unfortunately the normal core version of QParamics software does not record OD data for attempted releases; rather it only records this data for trips that manage to load onto the network. To overcome this problem a plug-in has been developed by Azalient Limited/Masson Wilson Twiney Pty Limited which reports measured statistics and calculated estimated travel times and distances for unreleased/partially completed trips. A sample of one of the spreadsheet files output by this evaluation plug-in is shown in Figure 4.

				Measured Totals										Estimated Totals			
				Count				Freeflow	Trip Time	Distance	Stops			Time	Distance	Stops	
				All	Cars	Light	Heavy	Time (min)	(min)	(km)	Cars	Light	Heavy	(min)	(km)	Cars	Light
OD	Internal	Internal	Complete	31	31			34.8	73.92	30.36	92						
			Incomplete	1	1			0.33	2.12	0.29	2			2.31	0.33	2.2	
			Total	32	32			35.13	76.03	30.65	94			76.23	30.69	94.2	
OD	Internal	External	Complete	422	410		12	326.4	785.8	275.3	890		22				
			Incomplete	9	9			2.74	8.31	2.16	10			17.17	5.96	21.31	
			Total	431	419		12	329.1	794.1	277.4	900		22	803	281.3	911.3	
OD	External	Internal	Complete	383	374		9	310.1	715	249.7	710		15				
			Incomplete	15	15			9.02	37.08	8.21	36			67.72	18.59	65.25	
			Total	398	389		9	319.1	752.1	257.9	746		15	782.7	268.3	775.3	
OD	External	External	Complete	2402	2354		48	2060	8569	1903	7599		159				
			Incomplete	123	121		2	40.09	319.4	38.2	224			731.1	106.1	558.6	
			Total	2525	2475		50	2100	8888	1941	7823		159	9300	2009	8158	
OD	All	All	Complete	3238	3169		69	2731	10144	2458	9291		196				
			Incomplete	148	146		2	52.18	366.9	48.86	272			818.3	131	647.4	
			Total	3386	3315		71	2783	10511	2507	9563		196	10962	2589	9938	
PT	Study		Complete														
			Incomplete														
PT	Other		Complete														
			Incomplete														
PT	All		Complete														
			Incomplete														
			Total														
All			Complete	3238	3169		69	2731	10144	2458	9291		196				
			Incomplete	148	146		2	52.18	366.9	48.86	272			818.3	131	647.4	
			Total	3386	3315		71	2783	10511	2507	9563		196	10962	2589	9938	

Figure 4 – Evaluation Plug-In Output (Partial Extract)

The basic summary statistics for count, time, distance, and number of stops are provided for complete, and incomplete trips in three sections, namely "measured", "estimated", and "derived". The measured statistics are taken straight from the model data for each OD pair while the estimated section includes a procedure to assess trip times and distance for incomplete trips. The derived statistics provide for vehicle measures including calculated costs for complete and incomplete trips.

The plug-in allows for user inputs to define;

- Reporting period, e.g. 15 minutes
- Economic road user costs
- Vehicle stop parameters

For this assessment, a stop was defined as vehicle speed being less than 5 kilometres per hour (kph) and not in motion again until speed exceeds 8 kph, rather than a simpler definition of a stop less than 5 kph. The use of 5 and 8 kph introduces hysteresis to prevent multiple stops being recorded for a vehicle whose speed hovers around 5 kph.

The method for estimating statistics is currently being tested and refined prior to including these statistics in a cost benefit analysis framework for simulation models. The aim is to have this analysis accepted by the RTA before presenting and distributing the full analysis framework (projected timescale end 2004).

For the purposes of this paper, the analysis is based on numbers of vehicles in the two classifications, complete and incomplete. The analysis also considers "delay" based on the time and distance as report by the plug-in, being the difference between actual and free flow conditions. The reporting of delay is not weighted by the number of stops which are reported separately.

Simulation Results

As described previously, test models were coded for three signal control strategies:

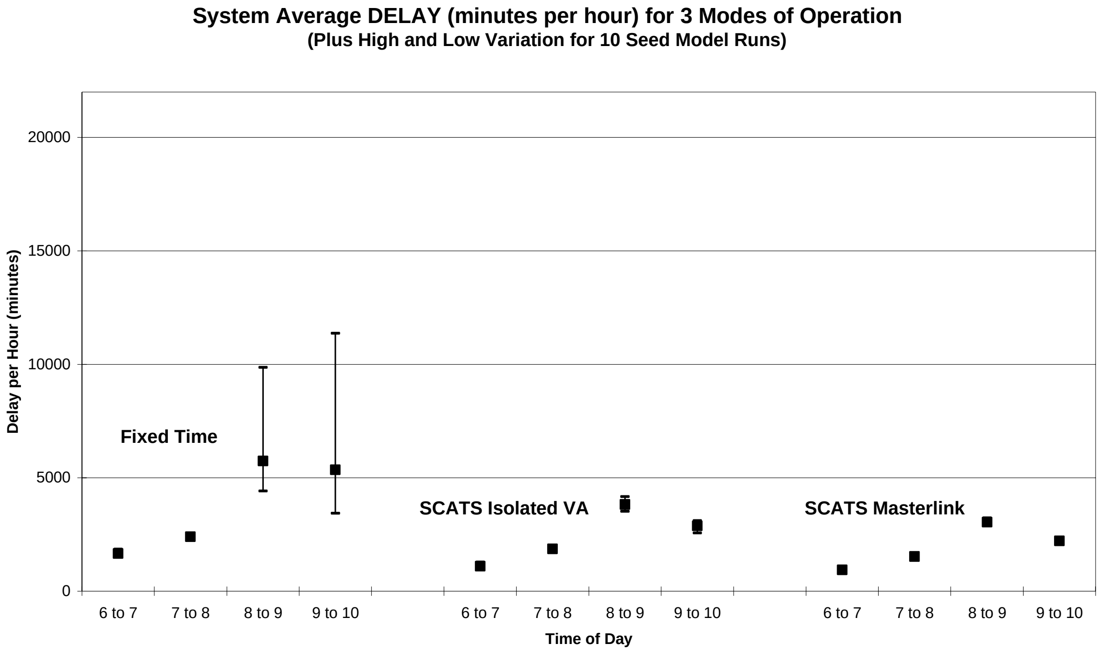
1. Fixed time co-ordinated
2. SCATS Isolated VA Mode
3. SCATS Masterlink (only 3 intersections in Masterlink)

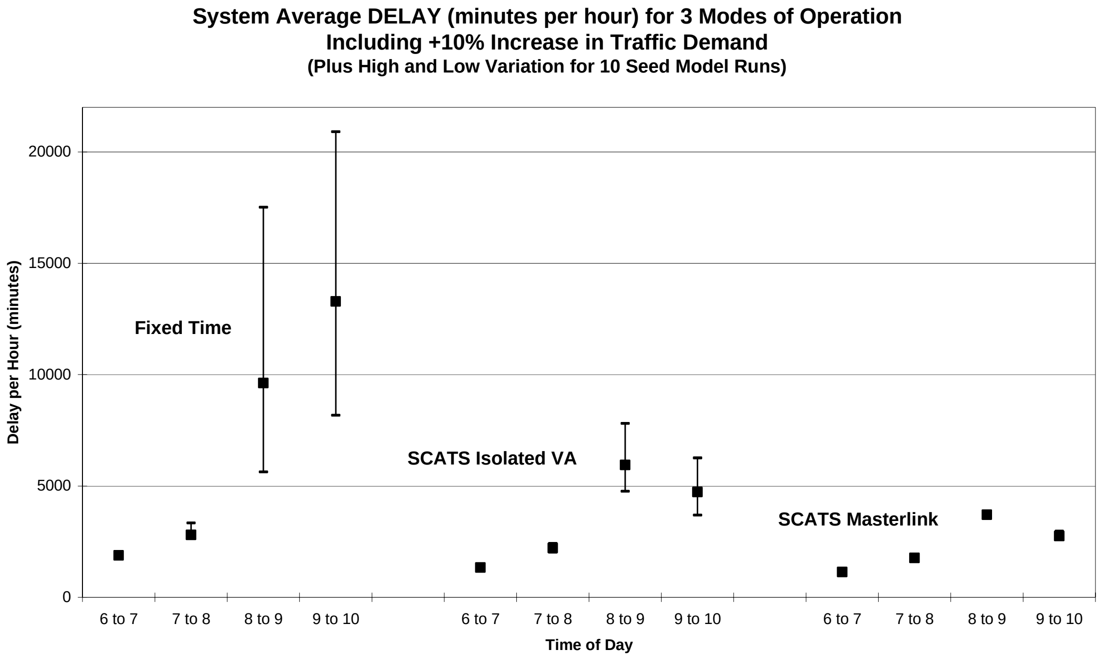
For each strategy, 10 model runs were carried out using different random seed values so that results could be compared for consistency and stability. The evaluation plug-in was used with each run to collect model operation statistics for the separate hourly periods of 6 to 7am, 7 to 8am, 8 to 9am and 9 to 10am. All simulation runs started with a 15 minute preload period, 5.45 to 6am. The evaluation plug-in measured and estimated traffic travel time and numbers of stops for each model run. Delay was calculated as the travel time minus the free flow time.

Additionally, the models were re-run with a ten percent increase in demand to reflect variations in demand that can occur in the real world due to seasonality or network incidents. While the random seed values produce varying patterns and intensity of vehicle release, the model still targets a constant demand over the modeling period.

Delay

Below are graphs of the average total delay in each hour for the 10 respective model runs for each mode of control. For each average hourly result, a vertical bar represents the high and low spread for the average delay arising out of model runs.





The results for each mode of operation logically show delay building up as demand increases. For low traffic demand, all modes of operation show similar levels of delay (although fixed time is higher). However as demand builds the mode that adapts best produces least delay.

For the runs shown in the first graph (average daily traffic conditions), the fixed time mode competes quite well with the two SCATS modes for the average values. This is to be expected as predictable traffic demand conditions can be well managed by an optimized fixed time plan.

However, once the demand varies from the average conditions, the fixed time mode delay varies markedly. The plots of delay for fixed time models show a large variation between the times recorded for each hour and indeed within the times during the hour 8 to 10am. In the +10% traffic demand scenario, the recorded delay has a variation range in excess of 200%, representing unreliable trip times.

In contrast, the average delay for the SCATS control modes is stable and consistent between each hour, and with varying demand.

Under SCATS Isolated VA control, delay remains stable over the operating period and only produces some variation under the increased demand scenario. The system adapts well, but has its limits.

Under Masterlink mode (only 3 intersections are in Masterlink) the results show very stable and consistent levels of delay. In relation to fixed time and isolated VA modes of operation, the delays are consistently lower, particularly in moderate to high traffic demands.

Stops

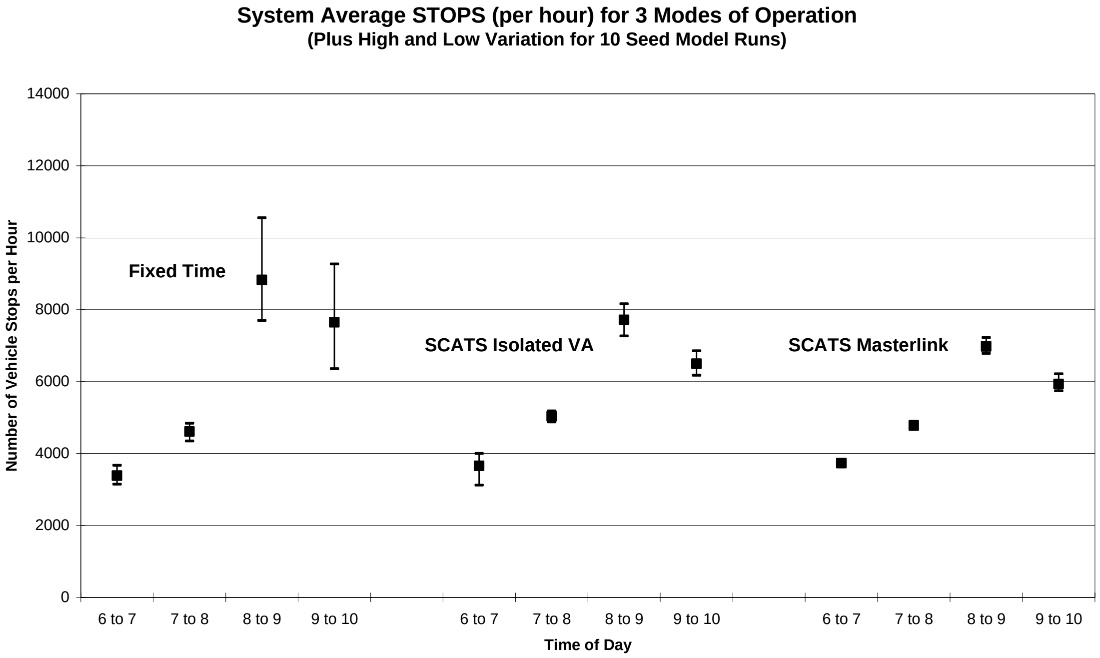
Graphs for stops are shown below. They reinforce the results shown in the delay graphs. Interestingly, stops for fixed time mode for 6 to 8am are lower than those for the corresponding SCATS control system (although delay is higher). This is explained by the fact that the fixed time models have been coded with all six intersections linked (coordinated). In Masterlink mode, only three of the modeled six intersections are linked.

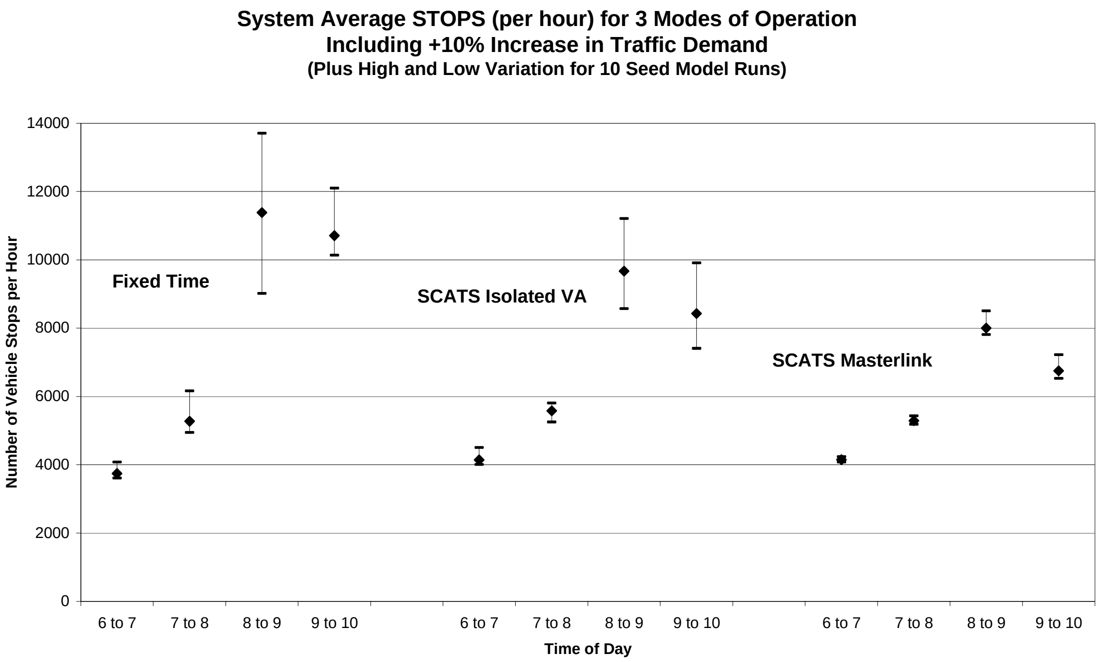
As the demand in the system gets to its highest levels (8 to 9am) the difference between stops for Isolated VA and Masterlink modes becomes larger. This indicates that coordination of signals in conditions approaching congestion levels will provide improved traffic operation.

At higher levels of demand (8 to 10am) the SCATS Masterlink control always shows lower average stops than the SCATS isolated VA mode.

In summary;

- Under low traffic demand the results for the 3 modes of operation are similar
- As demand increases the two SCATS adaptive modes start to out perform the fixed time mode
- Any variation in traffic demand under high demand conditions, is not handled well by the fixed time mode
- SCATS Masterlink mode shows superior performance under high demand with significantly reduced delay and number of stops compared to Isolated VA mode.





Conclusions

The use of the SCATSIM software and interface with simulation software, together with the devising of a suitable evaluation framework, have shown the benefits of SCATS adaptive signal control in preference to fixed time signal control.

Even though this evaluation methodology is still in preliminary stages of development, it confirms that because fixed time signal control does not react to traffic conditions, this control system can result in unrealistic operation in terms of performance (e.g. delay and number of stops). A great deal of care should be exercised to ensure that the coded fixed time cycle lengths, green splits and offsets are appropriate for the given traffic conditions.

In contrast, modeling using the SCATSIM interface produces consistent, stable, reliable and realistic results.

Additionally, the model results highlight the principle purpose of the SCATS adaptive control. That is: “to minimize overall stops and delay and to maximize throughput and minimize the possibility of traffic jams, when traffic demand is at or near capacity.” The SCATS Masterlink mode (coordination) is shown to perform better than SCATS Isolated VA mode particularly as traffic demand varies.

The SCATSIM software could be used for a variety of applications with potential major benefits for the implementation of adaptive control systems. Some of these uses are:

- to assess the benefits of implementing adaptive traffic signal systems
- to optimize the configuration of existing SCATS systems
- to test SCATS algorithms before real world application
- to train SCATS operators without affecting real traffic

- to test new road designs with SCATS control
- to test incident management systems

Ongoing work with a large simulation model of the Sydney CBD area (more than 200 signalized intersections) will include the use of SCATSIM. It is intended to use this model to further develop the evaluation process and produce further papers to report our findings.

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Disclaimer

The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessary reflect the views of the Roads and Traffic Authority of NSW, Australia.

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