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An insight into the economics that underpin the dynamic allocation of road space using traffic signals in New South Wales

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This paper provides insight into the economics that underpin the dynamic, real-time allocation of scarce road space using traffic control in New South Wales (NSW). We explain the history and status of the underlying system, SCATS, that was first created and is continually developed in NSW, and which has also been adopted across the other Australian states, and internationally. Using the results of traffic microsimulation modelling and empirical studies we provide evidence of the social benefit delivered to NSW by traffic control operation. We explain and defend the economic modelling and empirical economic analyses. This paper's contribution is the novel presentation of these facts and perspectives to the Australian economic community.

1. Introduction

This paper provides insight into the economics that underpin the dynamic, real-time allocation of scarce road space using traffic control in New South Wales (NSW).

We briefly explain the history and status of the underlying system, SCATS [1][2], that was first created and is continually developed [3] in NSW, and which has also been adopted across the other Australian states, and internationally.

In section 2 Economics:
We explain the experimental design and present the results of a comprehensive traffic microsimulation modelling analysis known as the SCATS and the environment study to provide evidence of the social benefit delivered to NSW by traffic control operation. We reference and discuss an innovative movie based on the traffic simulation that provides an intuitive, first person, customer perspective of SCATS contribution. We then explain the analysis workflow and field trial of an empirical study that is investigating the traffic and economic performance of specific SCATS algorithm changes.

This paper's contribution is the novel presentation of these facts and perspectives to the Australian economic community.

This presentation responds to the conference theme: economic challenges of today: answers from theory and practice.

SCATS

In 1970's, the Department of Main Roads developed a facility that was initially called the SCAT system [1]–now SCATS [2],[3]–to deliver sophisticated adaptive traffic control functionality to key roads within Sydney. SCATS was abbreviated from "Sydney Coordinated Adaptive Traffic System".

SCATS has grown and strengthened through organisational changes of the owning organisations: Department of Main Roads (DMR), the Roads and Traffic Authority (RTA), and now, the Roads and Maritime Services (RMS) [4]. These organisations have developed SCATS to deliver on their responsibility to dynamically manage the road network that spans the metropolis of Sydney and the regional cities, towns and roads within the state of New South Wales.

SCATS is being continually refined and updated to respond to the increasing and varying modern traffic management needs, and to leverage the advantages of new technologies. However, in this face of continuous change, the originating SCATS principles [1], [2] have proven enduring because of the demonstrated ability of SCATS to produce effective and robust traffic outcomes.

This paper provides a high-level insight into some of these principles from an economics perspective.

2. Economics

Economic modelling – SCATS and the environment study

In 2009 the RTA–now RMS, was approached to share it's expertise to inform the 2009 United Nations Climate Change conference in Copenhagen of the contribution that adaptive traffic control can provide to managing of carbon emissions that are generated from road vehicle activity. [5] The contact stimulated the RMS to initiate a study known as the SCATS and the environment (SatE) study to develop the appropriate evidence. [7]

The brief of the SatE study was to defensibly inform on SCATS contribution to environment issues and road customer benefits in terms of travel time savings and number of stops with their journeys through the studied network area.

Recent RMS investigations [*at the time*] indicated the difficulty of measuring traffic performance in the real world and defensibly attribute that performance to known changes in traffic signals policy. The solution adopted in the SatE study was to use calibrated traffic simulation as an estimating surrogate to real world measurement. [5]

Microscopic traffic simulation allows for a detailed model of a traffic network area and vehicle and pedestrian road users to be developed that recreates observed conditions for a given time period. The model is then calibrated and validated to the observations. This model is often termed the base scenario. Contrary scenarios are then developed that vary the base scenario to undertake what-if analyses. Differences in performance between the base and contrary scenarios inform on cause-and-effects.

The SatE study authentically operated the real SCATS system within a carefully constructed traffic simulation model. This allowed "modellers to operate the SCATS installation–as configured in the real world–to an equivalent virtual road network that was constructed in traffic simulation." [5] The same software and configuration that was used in the field was operated within simulation. SCATS measures vehicle and pedestrian actuations and sends directions to traffic signals that happened to be modelled devices interacting with modelled vehicles and pedestrians within the virtual world. However, SCATS sees the same authentic control problem, insofar that the model reflects the real world as indicated by calibration and validation performance.

The simulated traffic environment and road using agents–including vehicles, pedestrians and persons loading on and unloading off buses, was modelled using the Azalient Commuter [8] simulation application. [7] In a later subsection titled: Understanding performance from a driving customer's perspective, we reference a movie that is accessible to the reader via the internet that demonstrates the SatE study traffic simulation.

How to reveal SCATS operational value?

A challenge for the SatE project team was "how to reveal SCATS operational value?"

It was decided to model a base scenario that recreated the traffic conditions observed over a 24 hour period commencing at Wednesday 0300 25 November 2009. Wednesday day was chosen from analysis of the diurnal trends over two weeks. This revealed for the studied area and time that Wednesday was a weekday midpoint between weekend effects that were particularly evident on Mondays and Fridays. The start time 03:00 am was chosen as the hour of lowest flow to reduce the artificial boundary effects of starting and ending the model. Only the base scenario was calibrated and validated and these results can be found in the SatE study paper [7].

The next key question then was "what is a reasonable and realistic contrary scenario that could be compared to current SCATS operation?" The contrary scenario challenge was to ensure the study would produce representative real-world results that would be defensible and meaningful for real-world policy influence.

Real-world traffic control system installations are often highly configured by traffic engineers based on their learnt experience over long periods of time from operating the road network. This is true of NSW SCATS. Traffic control systems do not measure everything and therefore cannot learn or respond to all relevant matters. As a result assumptions are configured into the system by traffic engineers. For example, the traffic control system often cannot know when on-street parking is allowed or not, i.e. read the parking sign, and information on traffic control matters affected by this parking would need to be manually configured.

The configuration aspect of traffic control systems makes it difficult to readily create a synthetic example of an alternative system to SCATS for analysis that is defensible. This issues ruled out comparison to competing traffic control systems. Academic traffic modelling studies were ruled out as they are usually focussed research exercises that do not have the depth and dimensions to provide defensible realism.

The project team decided to use the configured Fallback (FB) mode of the SCATS installation as a valid contrary traffic control policy for comparison to normal SCATS operation that uses Masterlink mode (ML). The study comparison was then between the results of a base (ML) scenario and a contrary (FB) scenario. The SCATS normal operation and not FB was operational on the calibrated day and run similarly in the base scenario. The SCATS executables and configuration that was operated on the studied day were used for the base scenario. The base and contrary scenarios differed only by the ML and FB operating mode, respectively. In all other aspects those scenarios were identical including the individual modelled travellers and their origin and destination journeys.

ML employs SCATS adaptive traffic control operation known in SCATS parlance as strategic control. In contrast, the FB mode is a simpler operating mode that is manually maintained to be automatically used in the case of a systems fault, e.g. loss of communications. [7] The fixed time settings of FB are assessed and reconfigured if need be by RMS, and operated for a week period each year in the field to ensure the operation is appropriate.

Although simpler than ML, the FB is a sophisticated operation that utilises all the SCATS stop-line detectors in each lane. FB provides a degree of adaptive response to measured traffic conditions. The technical level of service offered by FB is comparable or better than many commercial traffic systems that are in many first world cities. Many cities still use fixed time traffic signals with simplistic or lesser measurement, and/or none or simple adaptive response.

This [*scenario comparison*] meant that normal SCATS operation was compared to an alternative, maintained and relied upon, traffic control policy. It also ensured that the SatE study produced immediate and tangible information value to RMS practice. [5]

Economic design of SCATS operation modes

The SatE study comparison of the base and contrary scenarios is of interest from an economic design perspective. The ML mode in principle optimises the traffic signal schedule to minimise spare capacity. The effect (in principle) is to maximise traffic throughput at the traffic signal site (this is more true in under-saturated conditions). The process explicitly trades-off competing movements. In this context, the ML mode can be considered an auction where movements bid with their measurements and compete with each other for traffic signal service.

In contrast to ML, the simpler FB schedules each movement in isolation that does not optimise and therefore does not-trade off competing movements. Essentially, FB movements greedily consume the traffic signal service up to a limit–if demand requires–of a maximum value that is profiled across the week as a pre-configured fixed time schedule.

The currency or price that is optimised in ML is normalised across all movements. This currency is a natural price that informs on the relative spare capacity of a movement during a traffic signal. In simple terms, the price is the percentage of (relative) wasted traffic signal time. The currency for a movement is relative to the efficient conditions calibrated at each lane/detector each previous day of the respective movement. The effect of this normalisation is that movements endowed with physical advantages, eg a downward grade promoting an efficient discharge of traffic (or disadvantages, e.g. a tight left hand turn requiring traffic to inefficiently slow down to negotiate the corner) have those effects removed from influence in the auction process. All movements are equal and compete on price relative to their respective efficient conditions. In SCATS parlance, this is called “equisat” or equal degrees of saturation. This efficiency-relative natural pricing results in a more equitable competition for traffic signal service that promotes the efficient use of scarce road space resources.

In contrast to ML, FB mode has no intrinsic normalisation of the currency underpinning control across movements. Manual configuration of the fixed time settings can be used to mitigate this issue. However, this is a blunt, inaccurate and unresponsive instrument compared to the self-calibrating, adaptive ML operation. For all purposes, it is reasonable to assume there is no ML-like normalisation in FB.

There is some evidence of the linkage between equity and efficiency outside of traffic in the general economy. For example in Ostry, Berg & Tsangarides (that was socialised by Gittens [10]) the authors present the finding from an analysis of a cross-country dataset that “lower net inequality is robustly correlated with faster and more durable growth, for a given level of redistribution.” In so far that the ML in the base scenario provides equity, the results of the SatE study shown later in this paper are congruent. This statement of similarity is assuming–with some reason–that the competitive microscopic activities within the traffic problem demonstrated in the SatE study could be considered a microcosm with similarities to the microeconomic activities in a national economy.

SatE study experimental design

The SatE study modelled a critical 6.5 km corridor of Military Road and Spit Road on the North Shore of Sydney, Australia (refer Figure 7 in the Appendix). The modelled network was a linear mainline with side streets modelled as stubs. A complete 24 hour period starting at 0300 was modelled. Over 169,000 private vehicle trips, 1,000 public transport vehicle trips and 43,000 person trips were individually modelled [*as microsimulation agents*]. The model consisted of 21 SCATS-controlled intersections and 39 priority [*giveway*] intersections. The significant road infrastructure characteristics of the corridor that were explicitly modelled included: a scheduled reversible lane (tidal flow) system, a bascule bridge with scheduled openings, scheduled parking restrictions and significant road grade. The scenario statistics are given in Table 1. [7]

Table 1 – Basic statistics of SatE study scenarios

	Base Scenario	Contrary Scenario
Study Area	6.5 km	6.5 km
Model Period	24 hours	24 hours
Represented Day	25th Nov 2009	25th Nov 2009
Number of runs	15	15
Private Vehicle Trips	169,131	169,131
Public Transport Services	1,311	1,311
Person Trips	43,044	43,044
SCATS Controlled Intersections	21	21
Priority Intersections	39	39
Number of Zones	66	66
Number of SCATS Detectors	151	151
Number of SCATS Signal Groups	124	124
Number of SCATS Phases	71	71
Signal Control Strategy	SCATS Masterlink	SCATS Fallback

SatE study results informing on travel, environmental and economic performance

The indicative, absolute performance for each scenario across all vehicles in total in the modelled corridor across the studied 24h is given in Table 2. For example, this table shows that traffic consumed an average across all runs in the base scenario of 18,629 hours total travel time. The variation of ±229 that is the confidence limits at 95% confidence level due to small differences between each run within the scenario.

The absolute and percentage differences between scenarios are given in Table 3. A positive value is a reduction in the base compared to the contrary scenario. The results indicate reductions of the base (ML) over the contrary (FB) scenario, for all vehicles of 28% travel time, 25% stops, 15% CO_2, 13% NO_x and 15% PM10-emissions.

Together, these traffic and environmental performance reductions were interpreted to provide an indicative, total opportunity cost savings of AUD $143,592 or 27% at 2009 values, for 24 hours across the corridor [7]. This economic estimate was based on unit valuations from the RTA Economic Analysis Manual [14] of the performance improvements listed in Table 3.

Table 2 – Physical mean performance of SatE study scenarios

Criteria	Base Scenario	Contrary Scenario	Units
Travel time	18,629 ± 229	23,895 ± 870	hour
Travel distance	501,245 ± 16	501,362 ± 33	kilometre
Stops	622,779 ± 9,094	780,361 ± 22,678	stop
CO_2	234,501 ± 1,811	268,741 ± 6,004	kilogram
NOx	835,271 ± 6,205	944,305 ± 19,904	gram
PM10	16,021 ± 121	18,439 ± 344	gram

Table 3 – Physical mean difference performance between SatE study scenarios

	Difference		
Criteria	Absolute*	Percentage**	Units
Travel time	5,266 ± 1,100	28% ± 6%	hour
Travel distance	117 ± 48	0% ± 0%	kilometre
Stops	157,581 ± 31,771	25% ± 5%	stop
CO_2	34,240 ± 7,815	15% ± 3%	kilogram
NOx	109,034 ± 26,110	13% ± 3%	gram
PM10	2,418 ± 465	15% ± 3%	gram

[* Absolute = (contrary - base) | ** Percentage = (contrary - base)/base]

The results of the SatE study demonstrated that–in the studied example–a travel efficient outcome provides an effective environmental outcome. However, the design of the study did not model the potential of induced demand that could occur due to the increased attractiveness of the improved travel performance. In other words, the more efficient travel on this route with SCATS ML operation could encourage more people to drive that corridor than if the inferior performing FB was employed. If this demand change occurred, the resulting environment outcome would need to be offset against the state that was given up with the demand change. Given the finding of the study, it is plausible that the environmental change would be zero-sum if any trip changes did not change the overall travel efficiency.

In synopsis, the SatE study finding demonstrated the relationship between travel efficiency and resulting environmental effectiveness.

Equity of travel, environmental and economic performance

The studied network-wide results of the SatE study left a question about the equity of the distribution of performance benefits across travellers, and travellers grouped by trip, using the network. For example, it could be that one group, e.g. main corridor travel, was significantly advantaged but this outweighed a lesser but still meaningful disadvantage on travellers travelling to or from side streets.

This equity question for vehicles was studied in Chong-White, Millar & Shaw 2013 [11]. (NB Pedestrian performance was analysed separately and is not discussed in this paper.)

The analysis revealed that: SCATS delivers a social benefit in total travel performances – travel time, speed magnitude and reliability (variability) is distributed across customers and trip-profiled customer groups more equitably for travel performance metrics but less equitably for emissions performance. From the perspective of the individual customer, this apportioning was considered valuable because travel time and stops are costed personally, whereas (arguably) the costs of emissions are borne by the broader society and/or effected local population. [11]

Understanding performance from a driving customer's perspective

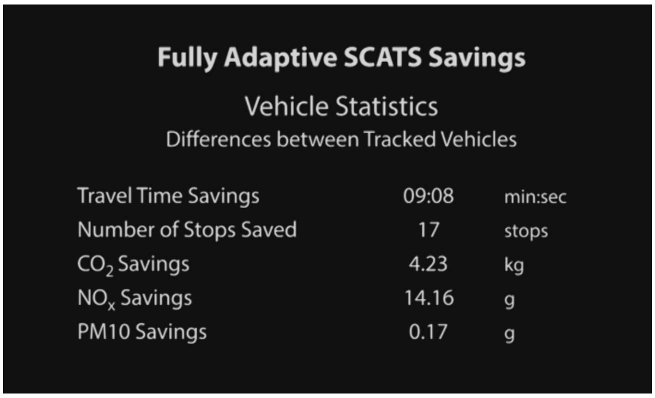
To provide intuitive meaning to the SatE study results a movie [12] was made using the traffic simulation that underpinned the study. The aim was to personify the SatE study results, by providing an intuitive, first person, customer perspective of SCATS contribution. [13]

The reference Kan Wah et al [12] provides an internet link where there movie can be played and the reader is encouraged (but not strictly required) to view this before reading the rest of this subsection. A screenshot from the movie is given in Figure 1.

The movie shows the base and contrary scenarios in split screen view, to the left and right, respectively. This is similar to a two player car racing computer game where each player sees their view of the world in the half screen. Each screen in the movie shows the same arbitrarily chosen car starting at 9:49 am (that occurs after the 03:00 am start of the model). This start time is at the end of what is often considered at location the morning peak. The car is travelling in-bound to the city that is a dominant direction in the morning peak; however, in the midday period (10:00-14:00) the flows are more balanced on the corridor. In each split screen view that same car travels the network where the model is identical except the operating mode of the signals within that scenario.

Figure 1 – SatE study visualisation screenshot

The visible difference in travel performance from the driver's perspective is visually perceptible and meaningful. As shown in the table from the movie in Figure 2 the inferior traffic signal operation in the contrary scenario imposed an additional 9 minutes and 8 seconds travel time and 17 additional stops on the car's travel compared to the base scenario. The trip time in the base scenario was 10:46 minutes. That table also shows higher emissions for that car in the contrary scenario.



Fully Adaptive SCATS Savings

Vehicle Statistics

Differences between Tracked Vehicles

Travel Time Savings	09:08	min:sec
Number of Stops Saved	17	stops
CO_2 Savings	4.23	kg
NO_x Savings	14.16	g
PM10 Savings	0.17	g

Figure 2 – Individual travelling car results from SatE study visualisation screenshot

The economic value of the travel time savings given in Figure 2 as experienced by an occupant in the simulated car can be calculated using the methodology employed in the SatE study [7]. Table 4 provides this calculated value for a travelling person trip taking a general trip. Implicitly, this value can be intimately perceived when watching the movie. The viewer of the movie having perceived the trip can make their own assessment as to the validity of the valuation.

Table 4 – Savings per travelling person in the simulated car at 2009 prices with SCATS ML

Activity	General
Travel time cost	$23.91
Travel time savings (hour)	1/3600 * (9 * 60 + 8 seconds)
Travel time savings ($ per person)	$3.64

This savings in Table 4 is the cost avoided by an occupant of the car from the SCATS traffic signal operation using ML as compared to the contrary case using simpler control with FB.

The $3.64 compares to the previously mentioned $143,592 savings across all traffic over 24 hours [7].[1] To estimate the economic value the SatE study followed the economic advice in [14] and we followed similar in the above calculation to align with the original work. This analysis averaged the 2009 business car and private car values and assumed a conservative 1 person occupant per car.

The RTA Economic Analysis Manual [14] that was used in the SatE study [7] has since been superseded by Transport for NSW, Principles and guidelines for economic appraisal of transport investment and initiatives [15]. To update and more fully exploit the available economic guidance we recalculate the movie car savings using the economic values in Table 1, Value Of Travel Time, Urban & Rural, p.231 in [15].

Given the Wednesday 10:00 am start time of the car trip it is reasonable to assume trips concerning both private and business activities would have occurred on that corridor. Accordingly, we use the values in the table that are provided in private car and business car categories. An urban category is used that is relevant for the studied road. The travel time savings experienced by a travelling person in the simulated car is given in Table 5. Using the categorised car occupant rates from the reference the travel time savings for the car is given in Table 6

Table 5 – Savings per travelling person in the simulated car at 2012 prices with SCATS ML

Activity	Private	Business
Travel time cost	$15.14	$48.45
Travel time savings (hour)	1/3600 * (9 * 60 + 8 seconds)	
Travel time savings ($ per person)	$2.30	$7.38

Table 6 – Savings per travelling simulated car at 2012 prices with SCATS ML

Activity	Private	Business
Occupants	1.4	1.1
Travel time savings ($)	$2.30	$7.38
Travel time savings ($ per car)	$3.23	$8.11

It is an interesting question–and a testing question as to the reasonableness of the valuations–to ask one's self after viewing the movie "would you be willing to pay these prices to achieve the improved travel experience in the SCATS scenario?"

As a comparison, the price of a public bus at that time to travel the same route is approximately $3.50 at 2015 prices with a travel time of approximately 26 minutes

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[1] The table of network totals in the movie has the CO_2 value wrongly shown that results in an incorrect total economic savings in that table. The results tabled in [7] are the correct values.

[16]. It should be expected that this bus travel time is estimated by the bus company with the implicit expectation that the road network is operating with SCATS using normal operation (ML) and is therefore aligned with base scenario of the SatE study. At a simple level, it is reasonable to assume that if the system was operating in FB then the bus would incur at least the additional travel time cost seen in movie incurred by the car in the contrary scenario. (NB The bus stopping at bus stops would complicate this estimate.)

Interpreting the performance from Sydney metro perspective

To interpret the SatE study results to Sydney metropolitan area the study results were extrapolated as shown in Table 3.

The first row of Table 3 shows the original SatE study corridor results. Three Sydney metro extrapolation methodologies are shown each on successive rows to inform on the calculations and assumptions. The extrapolated detail results follow the methodology used in [17] that used the technical dimensions of the intersections to support the extrapolation. The flow pro rata results proportion the extrapolated detail results by intersection average daily flow in the SatE study versus Sydney metro.

Figure 3 – Indicative savings for Sydney Metro with SCATS ML

Travel Time savings	**Time scope**	**SCATS sites (count)**	**Time savings (hour)**	**$ Savings† (AUD2014)**	**Methodology**
Corridor (SatE study)	Weekday WD year*	21	5,226 hour 1M hour	$140,945 $37M	Modelled
Sydney metro	Weekday WD year* % GRP**	2814	700,284 hour 182M hour	$19M $4.9B 1.6%	Extrapolated Simple ***
Sydney metro	Weekday WD year* % GRP**	2814	800,464 hour 208M hour	$22M $5.6B 1.8%	Extrapolated Detailed ****
Sydney metro	Weekday WD year* % GRP**	2814	519,971 hour 135M hour	$14M $3.6B 1.2%	Flow pro rata *****

* WD year is weekday year (5 * 52).
** Percentage of Sydney metro Gross Regional Product (GRP) that is given as 312.9B‡.
*** Extrapolation uses ratio of SCATS sites (2814/21).
**** Extrapolation uses technical dimensions of individual sites that included number of: lanes out, movements, vehicle signal groups.
***** The extrapolated detail results are multiplied by the ratio of average daily flow through all Sydney metro intersections dived by flow through SatE study intersections (39,300 / 60,500 = 0.65).

†Advised by [15] where values are at 30 June 2014 and value of travel time $26.97/h for urban light vehicle from Table 9 ‘Average hourly value for travel time per vehicle – urban’.
‡Advised by Deloitte 2012, “Infrastructure and the NSW economy”, Infrastructure NSW.

The extrapolated results in Table 3 indicate that the contribution of SCATS optimising traffic control is meaningful at 1.2% of the Gross Regional Product of Sydney metro.

Economic empirical analysis – SCATS algorithm trial

At the end of 2014 and continuing at the writing of this paper a SCATS algorithm trial is underway in Sydney. The algorithm trial is evaluating the performance of SCATS with specific option settings that affect the core decision-making variable of SCATS known by the variable DS and called “Degree of Saturation”.

DS is the currency of SCATS real-time optimisation. DS is normally expressed as a percentage and reflects the utilisation of a detector that instruments a specific lane at the approach to a SCATS site.

The information within DS can be considered the percentage of demanded flow versus possible flow on the detector. Possible flow is the calibrated capacity of the lane that is continuously updated by SCATS each day. Demanded flow is the estimated flow demanding to utilise that lane.

When DS=100% the lane is fully utilised; when less than 100% under-utilised. DS can be less than 100% due to either (1) lack of traffic demand or (2) lack of access, eg upstream blockage. Higher DS occurs because of (3) increased traffic demand, or (4) downstream congestion, eg downstream friction due to car reverse parking, where a deficit of lower realised flow to higher demanded flow occurs. Other SCATS metrics differentiate (3) and (4). SCATS allows DS values greater than 100% where utilisation is maximal but realised flow is less than efficient flow.

Of interest to the economic focus of this paper, the changes investigated in the trial are analogous to the removal of a price distortion and associated wealth transfer within an economy. It is in exactly this spirit that motivated the algorithm trial.

The algorithm trial removed factors that strengthened the competitive advantage of shorter green traffic signals to the detriment of longer green traffic signals at the one traffic signal site. The distortion artificially boosted the value of shorter traffic signal service and diminished the value for longer service. The effect is to take service from movements with long greens and transfer to movements with shorter greens. These factors are applied in recent versions of SCATS by default.

The origin of the design of the factors was based on practical experience operating the network. It is the author's experience that these experience-based innovations are very difficult to change or remove from production SCATS. This is because a risk assessment of a change is difficult to gauge.

When the algorithm was designed there was no comprehensive traffic simulation that could support algorithm analysis. SCATS originally was mostly designed and enhanced by trialling changes in production on the road network. Initial algorithm modelling was most likely done on paper and thought experiments. Now with ability to operate SCATS within off-the-shelf traffic simulation there is the possibility of trialling algorithm changes within the laboratory but also in a representative manner.

The algorithm trial workflow at the writing of this paper has been three stages: the first two stages using traffic simulation and the last a real-world trial that is underway. The first stage used a theoretical model, the second a representative model.

The [*first stage*] analysis used a simple traffic simulation model of a single: lane, stop-line detector and traffic signal. Sufficient traffic demand and traffic signal red length was created to cause a queue of homogeneous vehicular traffic at the stop line. The detector actuations in the traffic simulator during the green were individually measured. The queue discharged during the green and never extinguished during the green. [19] The DS (termed *%DemandedFlow* here) was calculated from the detector measurements with the factors turned on (as in production – 'Current SCATS') and 'off' (the focus of the 'field trial'). The results are shown in Figure 4 where the trial version without the factor is more pure to the measurement. The success of stage 1 was to demonstrate the obvious 'price distortion'. At face value, the distortion need not necessarily be incorrect if there is a phenomenon requiring its use – testing this motivated stage 2.

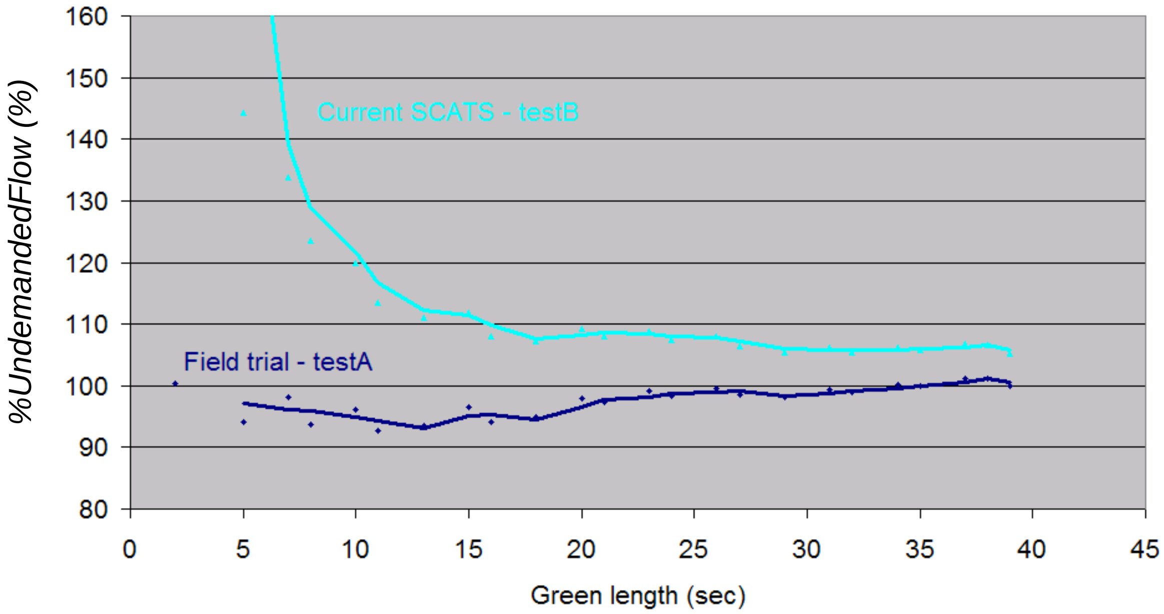


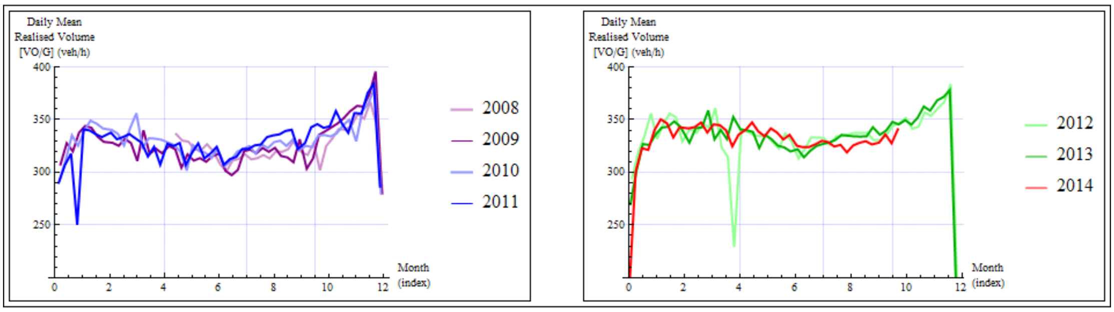
Figure 4 – Results from stage 1 of algorithm trial

Stage 2 of the algorithm trial used the SatE study model explained in the previous sub-section titled ‘Economic modelling – SCATS and the environment study’. The model had been updated for 2012 road conditions and traffic demand increased by 10% for congestion analysis reasons. [19]. The aim was to operate SCATS within the representative 24 hour model with the factors removed and compare to the base scenario that reflected current production. Results showed a 1960 hour or 7% reduction in total vehicle travel time across the studied 24h and model. This was valued at $43,000 at 2009 prices following the SatE study calculations [7]. The results were presented to RMS Network Operations who requested further analysis of directed trips on the corridor by peak periods to identify any disadvantages. This was called a “winners and losers analysis” that particularly was trying to identify any losers and related risks. The results–including from more forensic analysis than described here–were overwhelmingly positive and the decision for a field trial was given in the Taren Point (TAR) region, south of Sydney CBD.

The field trial was initiated mid 2014 and terminated late 2014 for other operational reasons. It was restarted early 2015 and ongoing at writing of this paper. The traffic performance during the first week of the trial was analysed closely in real-time, particularly during the high demand daylight hours, in case there were any significant unexpected consequences. None eventuated. After approximately two months a final analysis point was reached. An adjacent region Sutherland (SUTH) was used as a control reference that did not have trial changes employed. Results for 2014 indicated a conservative 853 hour or 9% reduction over 24 hour weekday in travel time through intersections due to the trial changes.

This stated reduction in travel time from the trial includes discounting for identified background variations identified in the control region and confirmed as a seasonal trend by analysing a multi-year longitudinal analysis across both regions. Refer Figure 5 which shows variations in daily mean *RealisedFlow* in TAR (top) and SUTH (bottom) and the obvious and consistent yearly characteristic evident in both regions.

SCATS STRATEGIC PERFORMANCE (SP) – TAR REGION – DAILY MEAN REALISED VOLUME ACROSS ALL DETS



SCATS STRATEGIC PERFORMANCE (SP) – SUTH REGION – DAILY MEAN REALISED VOLUME ACROSS ALL DETS

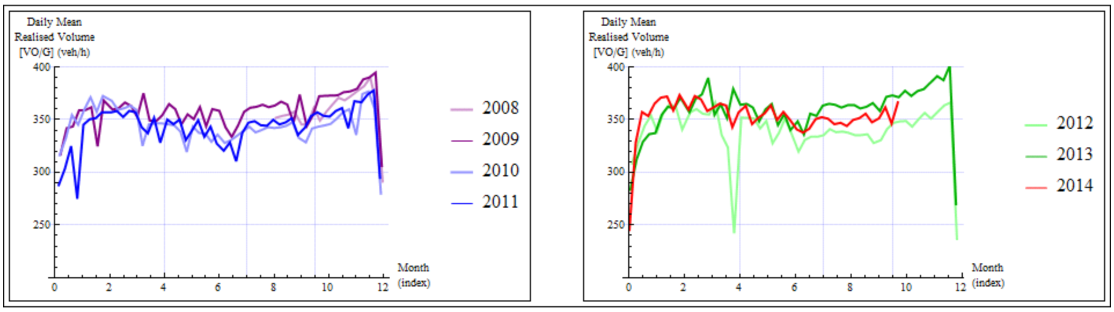


Figure 5 – Longitudinal analysis of RealisedFlow in TAR trial region and SUTH control region

Following the trial a post-analysis review was conducted to hold the estimations from traffic simulation in stage 2 accountable to stage 3 field trial results. The results of this review are given in Figure 6. The results are not "apples-to-apples" because the simulation study analysed a different part of the network than the field trial. However, at face value considering the differences, the estimated improvements were considered a reasonable (ie, similar order of magnitude) and therefore credible estimation of the eventual real world outcome.

- Modelling estimate*
  - Military Rd/Spit Rd, 21 sites, 24h Wed
  - 1,960h, 7%, $43k per weekday reduction
- Trial empirical analysis result**
  - TAR region, 29 sites, 24h Wed
  - 853h, 9%, $20k per weekday reduction

*Model measures network travel time including oversaturation.
**Trial measures travel time from red signal only. Trial has background noise.

Figure 6 – Results from post-analysis review of simulation estimations to field trial results

The trial is continuing and it is planned to expand it to another Sydney region. If the wider trial produces similar positive results then it is likely the changes will be eventually deployed across NSW with a new version of SCATS.

At face value it may seem surprising that a small algorithm change can produce such meaningful results. Questions can and have been asked: Why wasn't this done before?

Were the original factors wrong? The answer is it is hard to say without doing an intensive historical analysis.

SCATS is an ongoing developing system where that development responds to technological changes, policy changes and road customer changes including changes in traveller and driver behaviour. It is plausible that the factors may have been put in to mitigate actual issues or wider issues at the time (by intention or by unseen effect) that have since been removed, have disappeared or have mitigated with other changes – internal to the system or external in the world. It is also alternatively plausible that the factors were deployed at a wider scale than the original problem required but at the time (unlike today with traffic simulation) there was insufficient analytical ability to assess this at the required fidelity.

Another influence–alluded to above–is traffic management policy that responds to the characteristics of the road network, traffic demand and behaviour, and customers and stakeholders expectations. The economic-focussed objective function used to evaluate the algorithm trial may be different to the objective function(s) motivating traffic management at the time of the design of the factors assessed in the trial. For example, SCATS is installed in Sydney and Brisbane, Australia, and Singapore and Hong Kong (to name a few cities). The experience of the road network in each of those cases is often very different. Part of this is due to the different SCATS measurement, control and configuration choices by the owning authority. This phenomenon is analogous to how electricity market designs and implementations vary significantly in different locations, e.g. Australia’s NEM [20] and eastern U.S.A.’s PJM [21].

The algorithm trial demonstrates an example of operational reform underpinned by improvements in technical efficiency ([22], p.4) that is supported by theoretical, simulation and empirical–economic analysis. This is leading to real world improvement in road resource allocation and customer value. The trial is still underway with more questions posed and influencing than has been described here.

3. Conclusion

This paper provided an insight into the economics that underpin the dynamic, real-time allocation of scarce road space using traffic control in NSW.

The history and status of the underlying system, SCATS, was concisely explained.

We detailed the experimental design and results of a comprehensive 24 hour traffic microsimulation modelling study known as the SatE study. The study compared SCATS adaptive and optimising operation to an alternative maintained and relied upon, traffic control policy. The study results indicated that SCATS reduced vehicular travel times through the studied corridor network by 28% or 18,629 hours total over the 24 hours. Total number of vehicle stops and emission also reduced substantially. The total savings was estimated at $143,592 at 2009 prices across 24 hours, as an indication of the social benefit delivered by traffic control operation. These improvements were delivered equitably to customers across the road network and across their differing characteristic trips through that network. However, this was not true for emissions improvements which were distributed less equitably. This apportioning was considered valuable because travel time and stops are costed personally, whereas the costs of emissions are borne by the broader society and/or effected local population.

We referenced and encouraged the reader to view an online innovative movie comparing the two SatE study scenarios in manner like a two player car racing computer game. The aim was to personify the SatE study results by providing an intuitive, first person, customer perspective of SCATS contribution. Using an economic guide that reported 2014 prices we calculated that the car of focus in the movie, if undertaking a business trip, saved $7.38 per passenger from a travel time savings of 9 minutes. This translated to $8.11 for a business car trip. We also calculated private car value. For comparison, we showed that the ticket price of an equivalent bus trip was approximately $3.50 that incurred twice the travel time. The reader was then encouraged to make their own assessment as to the validity of the valuations from perceiving the trip from the movie.

We showed the indicative performance improvement contribution of SCATS optimising traffic control is meaningful at 1.2% of the Gross Regional Product of Sydney metropolitan area.

We explained an ongoing SCATS algorithm trial that is stage 3 of a project that is underway investigating the traffic and economic performance of specific SCATS algorithm changes in Sydney. The first two stages that preceded the field trial were also discussed that used: a theoretical model, and the representative simulation model, respectively. This together explained the economic analysis workflow: from theory to simulation to approval to field trial.

We argued the algorithm changes that are being investigated are analogous to the removal of a price distortion and associated wealth transfer within an economy. Results from the field trial in late 2014 indicated a conservative 853 hour or 9% savings over 24 hour weekday in travel time through intersections due to the trial changes. We presented the results of a post-analysis review that was conducted to hold the estimations from traffic simulation accountable to the field trial results. The estimates were considered a credible estimation of the eventual real world outcome. We concluded with a speculative discussion as to the possible reasoning for the historical algorithm choices that were under test in the trial.

This paper’s contribution is the novel presentation of these facts and perspectives to the Australian economic community.

This presentation responds to the conference theme: economic challenges of today: answers from theory and practice.

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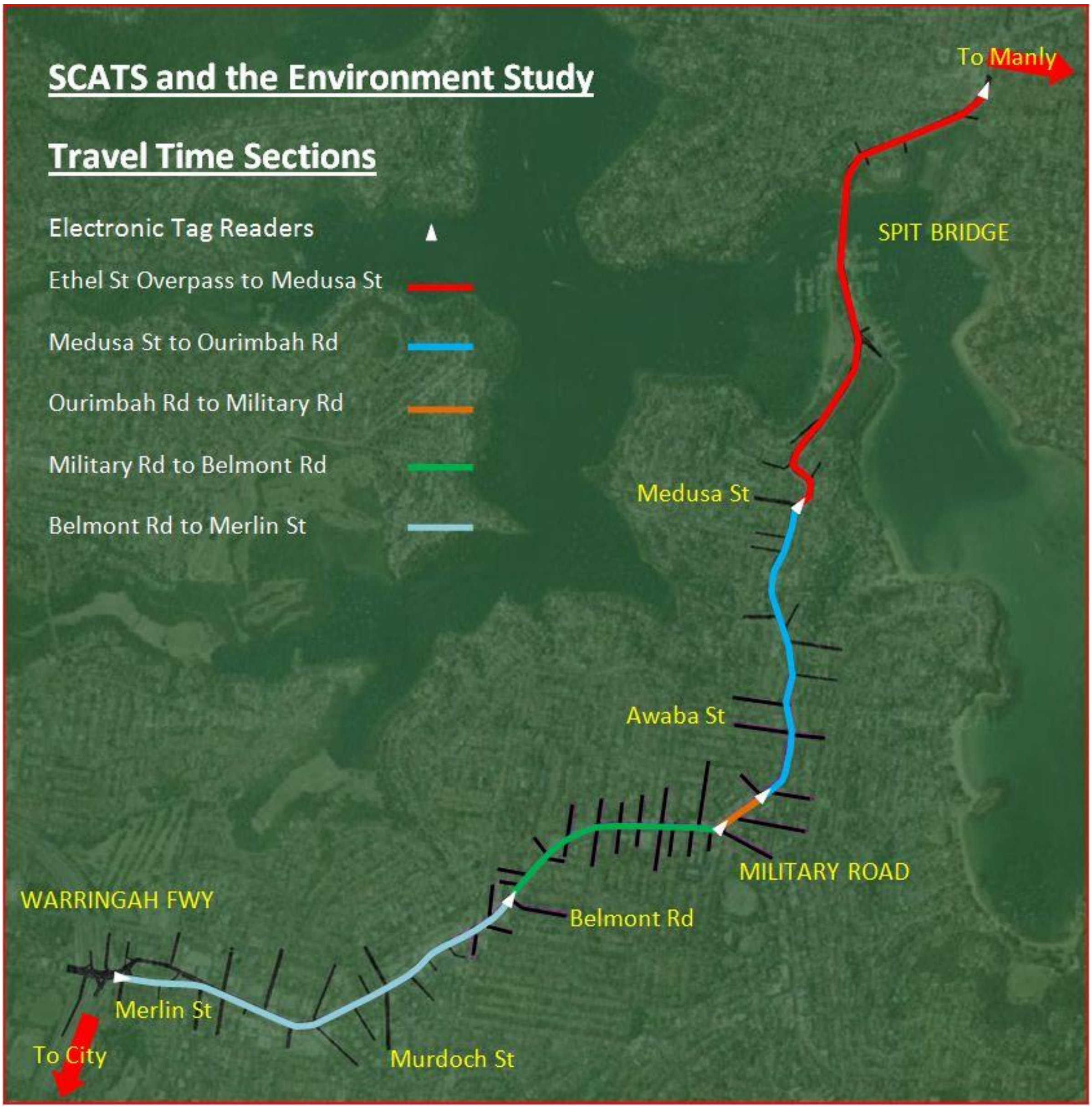

Figure 7 – Geographic area modelled in the SatE study showing travel time links