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SCATS and the environment study: an indication of road customer value

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

[1] Roads and Maritime Services
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@rms.nsw.gov.au

Abstract

The New South Wales (NSW) SCATS installation operates the 4000 traffic signal controlled sites on the road network that spans that state. A study named the SCATS and the environment (SatE) study by the RMS has previously demonstrated the indicative operational value that the NSW SCATS installation has delivered to NSW. Improvements were shown across all analysed vehicle measures including: travel time, stops; CO_2, NO_x and PM10 emissions; covering all vehicles for 24 hours of the studied network. To date these results were published only as total values at the network scale. These results can be considered indicative of the social benefits delivered by SCATS. This finding can reasonably motivate the question of how these social benefits are distributed across the customers who are using the network? This paper provides some answers. Analysis revealed that–generally–SCATS delivers characteristic network-wide 24 hour improvements in travel time and stops across: individual road customers and road customers grouped by trip. This finding was stronger for trips with median to higher costs. The results for emissions were varied. The implication is that SCATS delivers road customers broad traffic performance improvements in both magnitude and reliability across the road network and across their differing characteristic trips through that network. To achieve these traffic performance benefits, this comes at the cost of a less equitable distribution of emissions improvements. This analysis will allow a customer who uses the studied or similar network to better understand the value that SCATS provides to them, personally.

1. Introduction

The New South Wales (NSW) SCATS installation operates the traffic signal controlled sites on the road network that spans that state. These sites include instrumented: intersections, roundabouts and motorway ramps, which represent approximately 4000 sites in total.

SCATS is an intelligent transport system developed by Roads and Maritime Service (RMS).

A study named the SCATS and the environment (SatE) study by the RMS has previously demonstrated the indicative operational value that the NSW SCATS installation has delivered to NSW. Improvements were shown across all analysed vehicle measures including: travel time, stops; CO_2, NO_x and PM10 emissions; covering all vehicles for 24 hours of the studied network. To date these results were published only as total values at the network scale.

Given the network scale, the published SatE study results can be considered indicative of the social benefits delivered by SCATS, i.e. to the local society as a whole. This finding can reasonably motivate the question of how these social benefits are distributed across the customers who are using that network? This paper provides some answers. This allows a customer who uses the studied or similar network to better understand the value that SCATS provides to them, personally.

This paper complements the many existing papers that have investigated the performance of SCATS installations (e.g. Bastable 1980, Luk et al 1983, Chau & Al-Agha 2003, Peters et al 2008, Martin et al 2007, Stevanovic et al 2008, Stevanovic 2012).

In Section 2 the network level results of the SatE study are presented for background and context. In Section 3 the study design that underlies the analysis in this paper is explained. The contributions of this paper are to reveal as results in Section 4, and as analysis in Section 5, that:

- Generally–SCATS delivers characteristic network-wide 24 hour improvements in travel time and stops across: individual road customers and road customers grouped by trip. This finding was stronger for trips with median to higher costs. The results for emissions were varied.
- The implication is that SCATS delivers road customers broad traffic performance improvements in both magnitude and reliability across the road network and across their differing characteristic trips through that network. To achieve these traffic performance benefits, this comes at the cost of a less equitable distribution of emissions improvements.

Section 6 concludes this paper.

2. Background

The SatE study previously demonstrated the indicative travel, environmental and economic operational value that the SCATS intelligent transport system (RMS 2011a, Lowrie 1982) by the Roads and Maritime Services (RMS) (RMS 2013b) delivers to individual road customers of New South Wales (NSW). SatE study publications include: Chong-White et al 2010a, 2010b, 2011a, 2011b, 2011c, 2011d, 2011e, 2012a, 2012b.

Chong-White (2012a) previously reported that SCATS provided indicative physical total cost reductions for a 21 intersection corridor over 24 hours for vehicles of: 28% travel time, 25% stops, 15% CO_2, 13% NO_x and 15% PM10-emissions savings. This amounted to reductions in physical terms of: 5,266 hours travel time, 157,581 stops, 34,240 kg CO_2, 109 kg NO_x and 2,418 g PM10-emissions. (Chong-White 2012a). These savings can be interpreted as social benefits.

Chong-White (2012b) extrapolated the corridor results across the Sydney metropolitan network that comprised 2814 intersections for 24 hours. This indicated distance-normalised mean improvements of: 25% speed, 23% stops/km; and 8% km/CO_2, 16% km/NO_x and 21% km/PM10-mass emitted. This amounted to a mean performance increase of 5 km/h and decreases of: 0.4 kStop/km, 0.2 km/kg, 49.4 km/kg and 3.3 km/g. (Chong-White 2012b) (NB The different units are intended and the reasoning discussed in the paper).

3. Study design

3.1 How to measure SCATS operational value?

Recent RMS 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. (Chong-White et al 2012a, p.3) The SatE study measured SCATS operational value using calibrated and validated traffic simulation as an estimating surrogate to real world measurement.

The SatE study authentically operated the real SCATS system within a carefully constructed traffic simulation model using Commuter (Azalient 2013). The SCATSIM (RMS 2013c) facility was used that allows “modellers to operate the SCATS installation–as configured in the real world–to an equivalent virtual road network that was constructed in traffic simulation.” (Chong-White et al 2012a, p.2) Chong-White et al (2011d, p.4) explained that “SCATSIM ensures the operation [of SCATS] within simulation is realistic.”

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 1. 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. The model consisted of 21 SCATS-controlled intersections and 39 priority 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. (Chong-White 2012a)

The base scenario was developed to reproduce the traffic conditions observed in the field for the 24 hours commencing at 0300 25 November 2009. Calibration and validation results that indicate information quality and real-world relevance are provided in Chong-White (2012a).

3.2 How to reveal SCATS operational value?

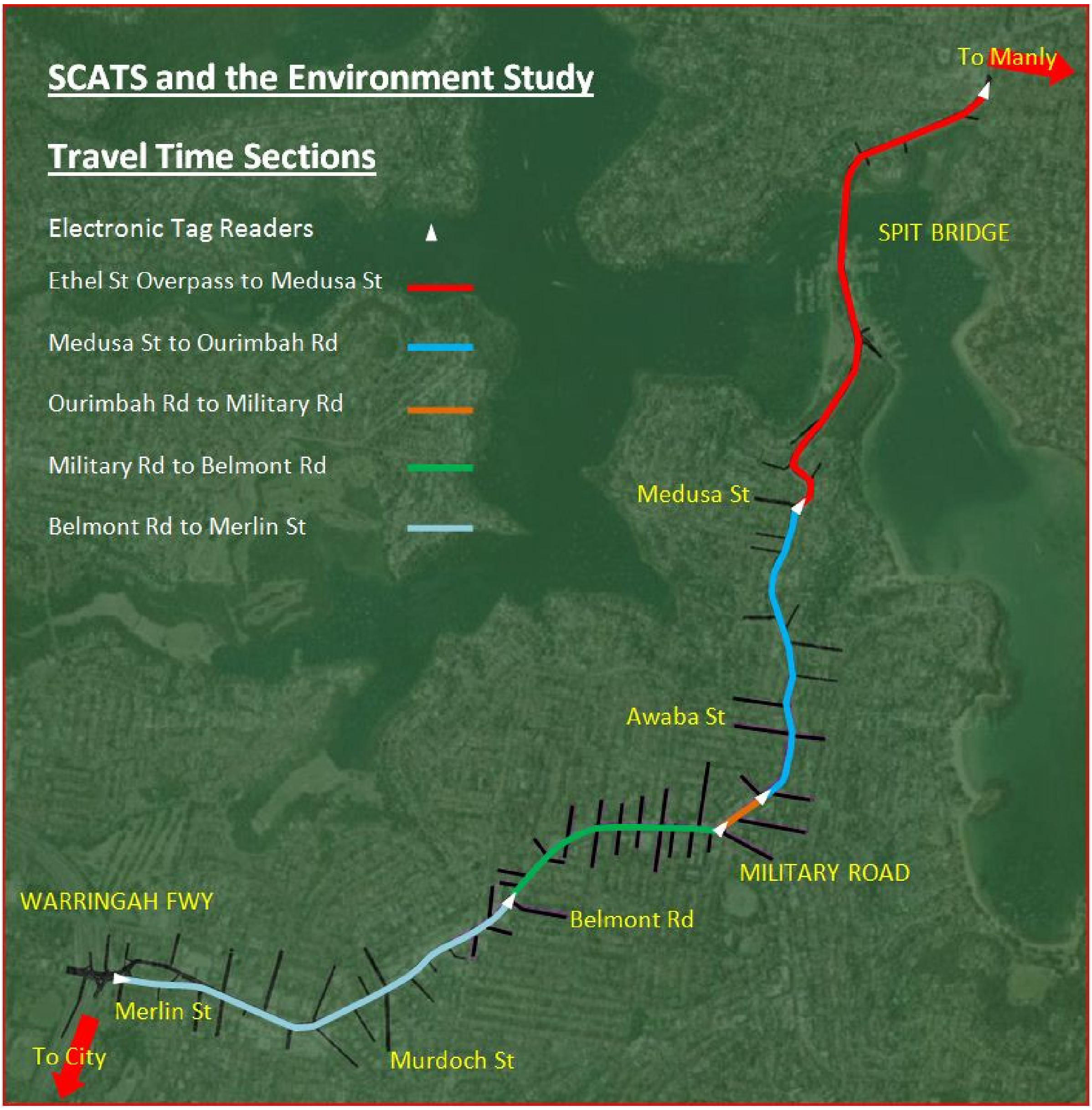
The SatE study compared the SCATS Fallback (FB) mode in a contrary scenario to Masterlink (ML) mode in the base scenario. The base and contrary scenarios were identical including model inputs differing only by the SCATS operating mode

SCATS ML employs ‘normal’ SCATS adaptive traffic control operation. In contrast, FB 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. Simply but pertinently, ML tracks the traffic state and adapts, optimises and trades-off traffic signal outcomes. In contrast, FB was predominantly fixed time with some reactive, adaptive traffic control capability. Importantly, FB does not optimise or trade-off. The comparison studied is therefore indicative of the value offered by SCATS more sophisticated adaptive and optimising traffic control operation.

3.3 Definitions of trip, route and journey

In this paper we define a particular *trip* as a desired travel between a defined origin location and destination location that are both located within the study area. A *route* for a given trip is the travel along a particular choice of connected roads that satisfies that trip. As the studied area involves no parallel paths there is no *route choice* for any trip and therefore a single mapping between trip and route. However, there is often *lane choice* along the route. A *journey* is the consumption of a trip by an individual vehicular road customer.

Figure 1: Model area of the 21 intersection model from the Main study – phase 2



3.4 How to assess the distribution of SCATS' social benefits?

This paper uses percentiles to summarise the distributions of journey performances across road customers. Customer journeys are characterised by: (1) a departure time–at the origin, and (2) an arrival time–at the destination, of the respective trip. Customer journey performances include: modelled road vehicle–(3) travel distance, (4) travel time, (5) number of stops; (6) CO_2, (7) NO_x, and (8) PM10-emissions emitted. The SatE study previously demonstrated the SCATS' social benefits across all performances. Here we analyse changes in the distribution of performances between the base and contrary scenarios to inform on the distribution of social benefits across customers.

Distributions of customer journey performances are analysed in two forms: Section 3.1 as modelled physical costs and Section 3.2 as reliabilities of those costs. Costs concern the magnitudes (or absolute values) and reliabilities concern the dispersion of the measures. Cost magnitudes are the cost of to an individual customer of consuming a journey, e.g. total travel time in minutes, and a distance-normalised cost where the journey cost is divided by the distance, e.g. minutes per km. Distance-normalisation allows performance comparison between trips of different spatial length.

The study analyses distributions of customer journey performances using two levels of aggregation: (1) across all modelled journeys without stratification; and (2) across all modelled journeys stratified by trips that will be referred to as trip-profiles. The first aggregation treats all modelled customers equal irrespective of the characteristics of their journey through the network. This informs on the distribution of social benefit across all customers generally. The second aggregation stratifies or profiles customers together within a group who consume a common trip, i.e. where all journeys within the group had the same origin and destination, across the modelled 24 hours and network. This informs on the distribution of social benefit across trip-profiled customer groups.

3.5 Notable caveat to consider

The analysis in this paper only used a single run from each scenario due to the significant data handling that was required for specific statistics. In the SatE study 15+ runs were originally completed and Chong-White (2012a) reported on those distributions using confidence intervals. The single runs for this study were judged by observation to produce approximately median results within the scenario. This paper therefore ignores the modelled uncertainty that was considered in Chong-White (2012a).

4. Study results

4.1 Customer journey performances

This section concerns the physical costs of customer journey performances without stratification. (Trip stratification is considered in Section 4.2.)

4.1.1 Indicative customer journey performances

This subsection investigates the distribution of customer journey performances across the modelled network and 24 hours. Table 1 presents the journey characteristics and Table 2 a percentile summary of performance of the two scenarios. Table 3 presents a percentile summary of the differences between scenarios of the performances in Table 2.

Table 1: Select percentiles of customer journey characteristics for both scenarios

Percentile	5th	50th	95th
Scenario	Both	Both	Both
No of modelled journeys	8,000	85,000	161,000
Journey distance	<0.5 km	3 km	7 km
Departure time	0700 hour	1400 hour	2300 hour
Arrival time	0700 hour	1400 hour	2300 hour

Note: hour is interval including ½ hour either side of clock hour, i.e. 0700 is 0630-0730.

Table 2: Select percentiles of customer journey performances for both scenarios

Percentile	5th		50th		95th		Units
Scenario	Base	Contrary	Base	Contrary	Base	Contrary	
Travel time	1	1	5	6	14	20	min
Stops	0	1	3	3	10	13	stop
CO_2 emissions	85	81	722	828	5172	5973	kg
NO_x emissions	<0.5	<0.5	2	2	21	25	kg
PM10 emissions	1	<0.5	8	8	434	547	mg

Table 3: Select differences of percentiles of customer journey performances for both scenarios

Percentile	5th	50th	95th	Units
Scenario	Contrary - Base	Contrary - Base	Contrary – Base	
Travel time	4 (9%)	25 (8%)	365 (43%)	sec
Stops	1 (0%)	0 (0%)	3 (30%)	stop
CO_2 emissions	-4 (-5%)	106 (15%)	802 (16%)	kg
NO_x emissions	<0.5 (-3%)	<0.5 (17%)	4 (19%)	kg
PM10 emissions	<0.5 (-7%)	1 (7%)	113 (26%)	mg

Note: To highlight differences, travel time units have been changed compared to Table 2.

Table 1 confirm the identical number of trips modelled in each scenario. Although unperceivable in Table 1 due to the rounding resolution, the journey distances between scenarios was similar due to the lack of route choice but did vary slightly due to lane changing. Departure times also did vary slightly in rare cases where queuing in the contrary scenario propagated back to the edge of the model forcing traffic to load onto the model network later than their scheduled time (NB this delay was captured in travel time measures).

Analysis of the change in profiles between scenarios inTable 2 identifies that the travel time distribution was pushed higher in the contrary scenario for longer duration trips as evidenced by larger positive differences in the higher percentiles with smaller positive differences for lower percentiles. A similar finding was evident for stops at the higher percentiles but no differences at the lower percentiles. This finding was different for CO_2 emissions where there was also a positive difference in the higher percentiles but contrasted for shorter duration trips with negative differences at low percentiles. Generally, the difference profile characteristics for NO_x and PM10 followed similarly to CO_2.

4.2 Trip-profiled customer journey performances

This section investigates the percentile distribution of trip-profiled customer journey performances across the modelled network and 24 hours. Two investigations are made:

- Subsection 3.2.1 investigates the '*central*' journey performance within the trip stratum across the trips. The trip median is used. This is to inform on how equitable the performance is distributed across trips.

- Subsection 3.2.2 investigates the *variability* of customer's journey performance within the trip stratum across the trips. The percentage median absolute deviation (PMAD) is used. This is to inform on how equitable the performance is distributed across customers within the trip.

4.2.1 Indicative trip-profiled customer journey performances

This subsection investigates the distribution of trip median performance across trips. Table 4 presents the percentile distributions of *distance-normalised* trip median performance for each scenario. Figure 2 plot select results from Table 4. Table 5 present the *non-normalised* equivalent of Table 4.

Table 6 presents the percentile distributions of the *distance-normalised* trip median differences between scenarios. Importantly, the differences reflect the change in median *in each trip* between scenarios. Figure 3 plot select results from Table 6. Table 7 present the *non-normalised* equivalent of Table 6.

Analysis comparing scenarios in Table 4 and Figure 2, and Table 5, identifies that the trip median travel time distribution for both distance-normalised and non-normalised cases was pushed higher in the contrary scenario. A similar finding was evident for the other performance metrics: stops, CO$_2$ and PM10. NO$_x$ differed slightly from the trend contrasting only that there was an almost insignificant increase in distance-normalised performance at the 50th percentile of the contrary scenario; otherwise the NO$_x$ profiled followed the trend.

Analysis of Table 6 and Figure 3, and Table 7, showed that the 50th percentile of the trip median difference was positive for travel time and CO$_2$ emissions. This indicated that more than half the *number* of trips had reduced performance in the contrary scenario. For the other metrics the 50th percentile difference was imperceptible indicating that a similar *number* of trips had reduced and increased performance. For the percentiles extremes the decreased performance at the 95th percentile was larger compared to the increased performance at the 5th percentile in the contrary scenario across for all metrics. This indicated that "the winners win was stronger than the losers lose" with the superior base over the contrary scenario.

Figure 2: Plots of select percentiles of trip median performances for each scenario

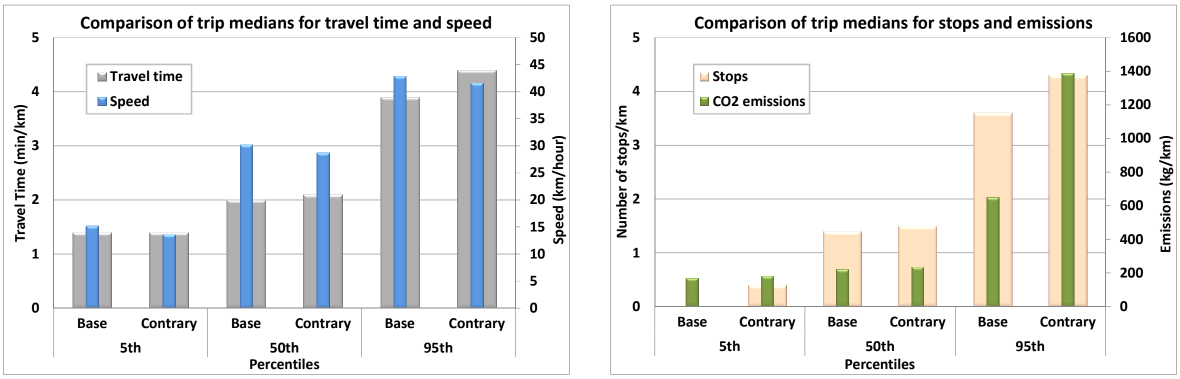


Figure 3: Plots of select percentiles of trip median performance differences between scenarios

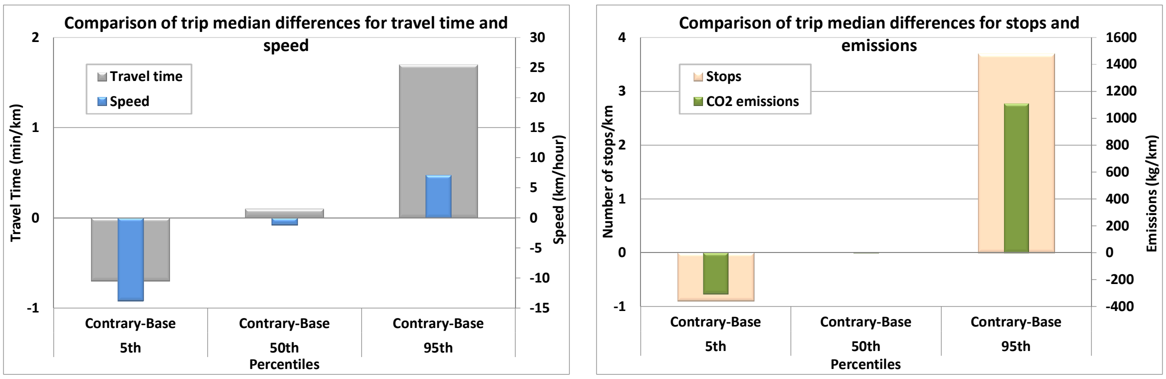


Table 4: Select percentiles of median trip-profiled customer journey performances for both scenarios (distance-normalised)

Percentile	5th		50th		95th		Units
Scenario	Base	Contrary	Base	Contrary	Base	Contrary	
Travel time	1.4	1.4	2.0	2.1	3.9	4.4	min/km
Speed	15.2	13.6	30.2	28.7	42.9	41.6	km/h
Stops	0	0.4	1.4	1.5	3.6	4.3	stop/km
CO_2 emissions	170	182	222	236	650	1389	kg/km
NO_x emissions	0.3	0.3	0.4	0.3	2.1	5.1	kg/km
PM10 emissions	1.3	1.3	1.6	1.6	41.5	41.6	mg/km

Table 5: Select percentiles of median trip-profiled customer journey performances for both scenarios (non-normalised)

Percentile	5th		50th		95th		Units
Scenario	Base	Contrary	Base	Contrary	Base	Contrary	
Travel time	1	1.1	4.0	4.2	9.7	11.2	min
Stops	0	1	3	3	6	8.5	stop
CO_2 emissions	74	125	462	545	1425	3416	kg
NO_x emissions	0.1	0.2	0.8	1.0	4.9	12.3	kg
PM10 emissions	0.5	0.9	4.0	5.1	87	184	mg

Table 6: Select percentiles of median differences in trip-profiled customer journey performance between scenarios (distance-normalised)

Percentile	5th	50th	95th	Units
Scenario	Contrary - Base	Contrary - Base	Contrary – Base	
Travel time	-0.7	0.1	1.7	min/km
Speed	-13.8	-1.2	7.1	km/h
Stops	-0.9	0	3.7	stop/km
CO_2 emissions	-307.5	3	1109.9	kg/km
NO_x emissions	-1.3	0	4.4	kg/km
PM10 emissions	-31	0	85.6	mg/km

Table 7: Select percentiles of median differences in trip-profiled customer journey performance between scenarios (non-normalised)

Percentile	5th	50th	95th	Units
Scenario	Contrary - Base	Contrary - Base	Contrary – Base	
Travel time	-0.9	0.1	3.9	min
Stops	-1	0	4	stop
CO_2 emissions	-572.4	6.3	2652.3	kg
NO_x emissions	-2.6	0	10.5	kg
PM10 emissions	-59.5	0	155.9	mg

4.2.2 Indicative equity of trip-profiled customer journey performances

This subsection investigates the distribution of trip performance variability across trips. Table 8 presents the percentile distributions of *distance-normalised* trip PMAD performance for each scenario. Table 9 present *non-normalised* equivalent of Table 8.

Table 10 presents the percentile distributions of the *distance-normalised* PMAD differences between scenarios. Importantly, the differences reflect the change in PMAD *in each trip* between scenarios. Table 11 present *non-normalised* equivalent of Table 10.

Table 8: Select percentiles of PMAD trip-profiled customer journey performances for both scenarios (distance-normalised)

Percentile	5th		50th		95th		Units*
Scenario	Base	Contrary	Base	Contrary	Base	Contrary	
Travel time	5%	4%	16%	18%	35%	51%	min/km
Speed	1.7%	1.4%	3.8%	3.3%	12%	30%	km/h
Stops	0%	0%	33%	34%	100%	100%	stop/km
CO_2 emissions	4%	2%	17%	11%	70%	74%	kg/km
NO_x emissions	2%	1%	10%	4%	85%	89%	kg/km
PM10 emissions	5%	2%	19%	9%	97%	96%	mg/km

*Note: Values in percent. Units of underlying data shown.

Table 9: Select percentiles of PMAD trip-profiled customer journey performances for both scenarios (non-normalised)

Percentile	5th		50th		95th		*Units
Scenario	Base	Contrary	Base	Contrary	Base	Contrary	
Travel time	5%	4%	16%	18%	35%	42%	min
Stops	0%	0%	20%	33%	100%	100%	stop
CO_2 emissions	3%	2%	17%	11%	61%	57%	kg
NO_x emissions	2%	1%	10%	4%	77%	70%	kg
PM10 emissions	5%	2%	19%	9%	95%	93%	mg

*Note: Values in percent. Units of underlying data shown.

Table 10: Select percentiles of PMAD differences in trip-profiled customer journey performances for both scenarios (distance-normalised)

Percentile	5th	50th	95th	Units*
Scenario	Contrary - Base	Contrary - Base	Contrary - Base	
Travel time	-12%	2%	26%	min/km
Speed	-12%	2%	28%	km/h
Stops	-48%	0%	50%	stop/km
CO_2 emissions	-52%	-4%	34%	kg/km
NO_x emissions	-68%	-4%	55%	kg/km
PM10 emissions	-88%	-7%	61%	mg/km

*Note: Values in percent. Units of underlying data shown.

Table 11: Select percentiles of PMAD differences in trip-profiled customer journey performances between scenarios (non-normalised)

Percentile	5th	50th	95th	Units*
Scenario	Contrary - Base	Contrary - Base	Contrary - Base	
Travel time	-12%	2%	26%	min
Stops	-50%	0%	50%	stop
CO_2 emissions	-52%	-4%	34%	kg
NO_x emissions	-68%	-4%	55%	kg
PM10 emissions	-88%	-7%	60%	mg

*Note: Values in percent. Units of underlying data shown.

Analysis of the PMAD of travel time and emissions in Table 8 indicates the contrary scenario was pushed higher at the 95th percentile. This was also true for travel time and stops at the 50th percentile; in contrast, the 50th percentiles for the three emissions were lower. The 5th percentiles were very low values but generally there was an increase in variability in the base scenario at the low end of the distribution (5th percentile). At face value, this result suggested that SCATS reduces the variability of journeys costs within trips with high (and median for travel time only) performance costs per unit distance travelled but increases the variability of journeys emissions costs within trips with median or lesser percentile costs per unit distance travelled, in the studied network.

Analysis of the non-normalised PMAD distributions in Table 9 indicates a similar finding to the distance-normalised case with notable exceptions including: a reduction for variability of stops per trip at the median, a decrease in variability of emissions per trip for emissions at extreme positive end of the distribution in the contrary scenario.

Considering the non and normalised findings together highlight that SCATS is: redistributing the variability of stops across different trips but without significantly changing the per distance stop variability across trips; and similarly redistributing emissions with an increase in per distance emissions variability across trips. Travel time variability shows consistent reduction.

Analysis of the PMAD differences in Table 10 and Table 11 indicate a general increase in variability of the traffic metrics: travel time and stops, and a decrease in variability for emissions metrics, across trips in the contrary scenario. This can be seen by the larger 95th percentile change for the traffic metrics compared to the 5th percentile; the reverse is true for emissions. Also, the traffic metrics had an increase at the 50th percentile and the emissions a decrease in the contrary scenario. These findings suggest that SCATS is achieving traffic performance reliability improvements (less variability) but higher variability for emissions within trips.

5. Analysis

Broadly–the journey performance findings indicate the benefit that an individual customer receives from SCATS optimising and adaptive control for a general trip through the studied network is:

- They receive substantial traffic performance benefits across all studied metrics if their performance cost of interest is equal to or higher than the median cost. (NB Stops was an aberration to this trend at 50th percentile with no perceptible difference.)
- This statement is also true where their performance cost is less than the median but only for travel time and stops. In contrast, there was a decreased emissions performance for low emitters. Emissions across the network in total decreased, i.e. total emissions performance increased, but these results indicate there was a redistribution in the base scenario increasing the emissions of lower emitting trips and (comparatively stronger) reducing emissions of higher emitting trips.

Broadly–the trip-stratified findings indicate the benefit that a trip-profiled customer group receives from SCATS optimising and adaptive control for a general trip through the studied network and 24 hours is:

- Generally, the trip-profiled groups receive trip median performance benefits across all studied metrics across the studied percentiles.* (*NO_x was a minor aberration to this trend.)
- The median performance gains of the trip-profiled groups that are advantaged substantially outweigh the losses of the trips that are disadvantaged. This was true both for the magnitude of performance improvement and the number of trips improved (which was more evident for travel time and CO_2 emissions).
- Generally, trip-profiled groups receive performance reliability benefits (reduced variability) for traffic metrics: travel time and stops. For emissions, distance-normalised emissions reliability for extreme unreliable trips decreased; otherwise there was a decrease in emissions reliability.
- The reliability performance gains for travel time and (to a lesser extent) stops outweighed the losses of trips that were disadvantaged. This was true both for the magnitude of reliability improvement and the number of trips improved. The reverse is true for emissions.

Insofar that the analysis as applied is an indicator of the equity of the distribution of performance across customers generally, and separately within the trip, the results can be interpreted that SCATS overall improved customer equity for traffic metrics and decreased equity for emissions. This was found across both the trip median and trip variability (PMAD).

6. Conclusion

This paper demonstrates the indicative travel, environmental and economic operational value that the SCATS intelligent transport system by the RMS delivers to individual road customers. The analysis covers 24 hours of a key arterial corridor on the North Shore of Sydney, Australia. Results are derived from a widely published study known as the SatE study. The study compared a base scenario demonstrating SCATS to a contrary scenario.

Performance metrics analysed included: travel time, stops; CO_2, NO_x and PM10-emissions. The previous results from the SCATS and environment study (Chong-White 2012a) indicated that across the network for 24 hours there was an overall benefit for all performance metrics. Simply, this can be interpreted that SCATS produces a net social benefit. This paper assesses how these social benefits were distributed across the individual road customers using the network. This interpretation allows a customer who uses the studied or similar network to better understand the value that SCATS provides to them, personally.

In summary, SCATS delivers a social benefit in total travel performances – travel time, speed and stops, and emissions performance – CO_2, NO_X and PM10. This benefit in terms of 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 is 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.

The implication of the findings of this study for road customers is that SCATS delivers them broad real traffic performance improvements for both magnitude and reliability across the road network and across their differing characteristic trips through that network. To achieve these traffic performance benefits, this comes at the cost of a less equitable distribution of emissions improvements.

The implication of the findings of this study for SCATS users and potential users is that they can deploy and use SCATS knowing that: traffic performance improvements are equitably distributed across the travelling road customers, but in contrast, emissions improvements are (comparably) not equitably distributed. This suggests that where resulting local effects from emissions are deemed critical that accommodating SCATS policies and configuration practices may be required.

It is important that practitioners using this paper must interpret the results and findings with consideration of the characteristics of the road network testing including the artificial scope of that modelled network and modelled vehicle trips through that modelled network.

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