

SCATS RAMP SIGNALLING - SAFETY & OPERATIONAL OUTCOMES IN AUCKLAND NZ

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ABSTRACT

This paper summarises an assessment of the performance outcomes of the ramp signalling (metering) system installed progressively over most of the motorway system in Auckland (NZ).

Objectives for this assessment include:

- Evaluating data on the relative safety performance;
- Identifying improvements in bottleneck throughput and speeds; and
- Discussing the improved operation of weaving areas subjected to ramp metering.

This paper has been prepared to describe and summarise the safety and operational outcomes of the Auckland Travel Demand Management (TDM) project, in particular those outcomes that could be directly associated with the use of the Roads & Marine Services (R&MS) NSW's SCATS Ramp Metering System (SCATS RMS) for the Auckland TDM project undertaken between 2005 and 2010.

The paper covers:

- The broader assessment of safety outcomes involving all severities of crashes;
- A refined assessment of peak period and periods through which ramp signalling generally operated;
- An assessment, where practical, of casualty crashes during peak period and periods through which ramp signalling generally operated;
- Operational improvements (generally speeds and throughputs) in sections of motorway where other capacity upgrade works did not influence performance.

The findings included:

- Productivity (increased throughput): between 1% and 15% at critical bottlenecks;
- Average speeds increases: up to 14 km/h across both peaks combined with significant increases in flow rates;
- Annual delay savings: Southern Motorway/Curran Street and Northwestern Motorway – about 350,000 hours per annum with the group of sites studied have generated annual travel time savings of around \$7 m;
- Crash reductions: around 32-34% outbound and 17% inbound;
- Successfully resolving major flow breakdowns in several high-volume weaving areas.

INTRODUCTION

Scope of Initial Study

The initial research was commissioned by Roads & Marine Services (R&MS) NSW, in conjunction with New Zealand Transport Agency to assess the 'before & after' outcomes from the ramp

signalling project. The project commenced with a ramp signalling trial installation the success of which formed the basis of approval to a major project to ramp signalling the whole of the Auckland motorway system implemented over a 4-year period from 2007-8.

The initial internal research paper was prepared by O'Brien Traffic and focused on the safety and operational outcomes from the Auckland ramp signalling project and its associated use and application of the SCATS RMS algorithm. The paper covers:

- The broader assessment of safety outcomes involving all severities of crashes;
- A refined assessment of peak period and periods through which ramp signalling generally operated;
- An assessment, if practical, of casualty crashes during peak period and periods through which ramp signalling generally operated;
- Operational improvements (generally speeds and throughputs) in sections of motorway where other capacity upgrade works did not influence performance

This Paper

This paper presents the methods and key findings from the crash statistics review component of the wider study supplemented by selected extracts from the wider study relating to the current road rules, left-turn treatment implementation guidelines and detailed reviews of every single crash involving a pedestrian at slip lanes.

Study Methodology

It was proposed to use a study methodology as follows:

- Provide a description of the operating characteristics before and after implementation of the TDM project on each motorway;
- Carry out a sample analysis of the crash data within the operational 'area of influence' of a selection of sites;
- Provide a discussion on the outcomes of the safety analysis and the likely reasons for changes in safety levels;
- Carry out a sample analysis of speed and volume data at all sites where data was available in the vicinity of some ramps or over a section of a route using the existing 3-minute data derived from Auckland's ATTOMS (Auckland Transit Traffic Operations Management Service) system;
- Provide a discussion on the operational outcomes demonstrated by the analysis and the likely reasons for changes in operational characteristics;

The Southern Motorway and Northwestern Motorway are the main focus of the study as these were mainly free of any capacity changes created by roadworks. Nearly all work was done in calendar year 2008, so we have analysed 2005-7 (before) and 2009-2010 (after). 2010 was the latest year of crash data available in a suitable format.

Study Area and Characteristics

The study area used in the investigation was the motorway network of the Auckland Regional Area (population > 1 million). The existing and future State Highway (SH) network is shown in **Figure 1** – the brown routes being SHs and the red overlaid sections being the motorway segments that have had ramp signalling (ramp metering) installed.

The SH network is managed by the New Zealand Transport Agency (NZTA). All other roads in the Auckland area are under the control of local government. At the time of the implementation of the ramp signalling project (undertaken as a subset of a wider Travel Demand Management (TDM) project), there were five local government bodies involved. These have since been amalgamated into a single authority with its management undertaken by Auckland Transport. The Auckland CBD is located immediately north of the indicated 4-leg Central Motorway Junction (east of Herne Bay).

The Northern Motorway extends from the CBD across Waitemata Harbour to Albany and beyond. The Southern Motorway extends from the CBD through Manukau to the south, the Northwestern Motorway from the CBD to the west to Westgate, and the Southwestern Motorway from Manukau to north of Hillsborough. Auckland's biggest transport project is currently underway to link the Southwestern Motorway to the Northwestern Motorway via the "Waterview Tunnel" project.



Figure 1 - Map of Auckland Motorway Network (Source: NZTA)

To assist the reader in locating the various interchanges that are discussed in following sections a screen from the NZTA travel speed monitor, shown in **Figure 2**, has been inserted. The yellow arrows have been added to indicate the connection points between the motorways.

BEFORE AND AFTER OPERATING CHARACTERISTICS

Central Motorway Junction Area

The Central Motorway Junction upgrade works (about NZ\$130m) were being completed as the TDM Project started implementation in the field. The upgrade included works that created a new motorway to motorway connection between the Northern Motorway (SH1) and the Northwestern Motorway (SH16 W) and Grafton Gully (SH16 E). The two northbound ramps joined prior to then joining the Northern Motorway (SH1 N). This connection had ramp signalling operating at opening – the fourth ramp in Auckland to have ramp signalling. These two major connections had the effect of redistributing traffic in and around the Auckland CBD.

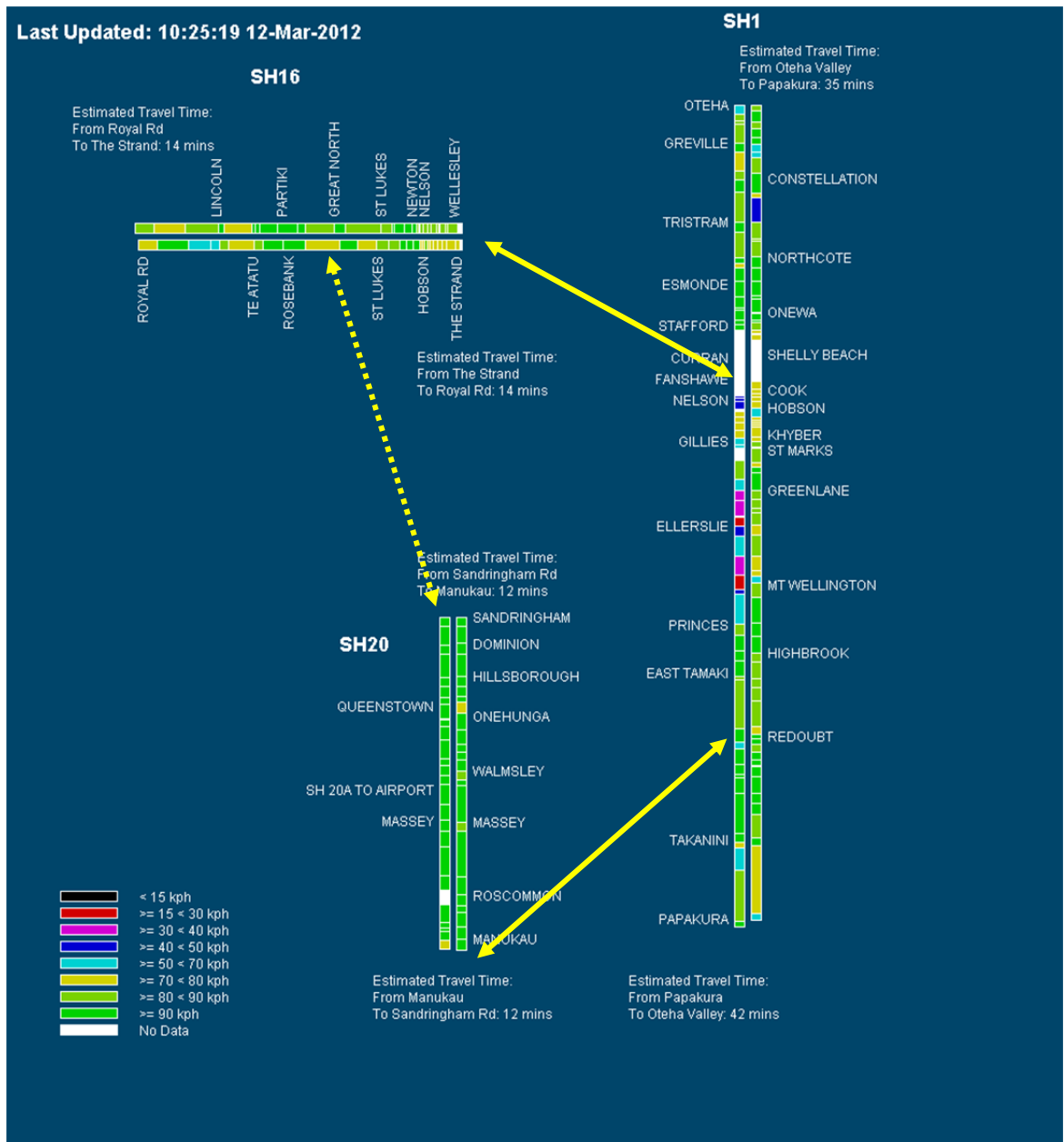


Figure 2 – Travel Speed Conditions Monitor

- Traffic relocated from the route along the northern edge of the CBD to the new Grafton Gully-Northern Motorway connection – adding up to several hundred vehicles per hour (vph) to demand for the new route in the critical PM peak;
- Similarly, traffic between the Northwestern Motorway and the Northern Motorway now had a direct connection with the demand shifting from the local network to the new connection – also a demand of about several hundred vehicles per hour (vph) for the new route in the PM peak.

The net effect of these two new connections was to increase demand on an already saturated link of the motorway – Wellington Street on-ramp to Fanshawe Street on-ramp. Despite the ramp signals at both Wellington Street and the new ramp being metered very restrictively, the link could not cope with the extra demands, and the mainline queues regularly extended back down the Southern Motorway for up to 15 km from around 4:30 pm. This impacted severely on the PM peak operation of the ramp signalling subsequently introduced for northbound ramps to the south of the Central Motorway Junction. The Central Motorway Junction bottleneck congestion has recently (April 2012) been relieved with the completion of the third northbound lane through Victoria Park.

Southern Motorway

Most early ramp signalling implementation took place on the Southern Motorway. To allow for potential unexpected operating system problems the initial sites were outbound at the southern urban fringe where congestion was not significant. The most severely congested sections of the Southern Motorway to be targeted by the ramp signalling were from the Auckland CBD to Gillies Avenue (4 southbound on-ramps), Gillies Avenue northbound on-ramp, and the northbound and southbound sections from St Marks Road to Mt Wellington Highway.

The operation of the ramp signalling system was constrained by a policy decision to limit the extent of queuing from ramps – thus there are many locations where flow breakdown occurred post ramp signalling.

The motorway is at or near capacity in each direction over most of the length between the Gillies Avenue and Mt Wellington Highway in each peak period. Hence the operational strategy was to maximise throughput at the critical bottlenecks. Equitable distribution of access to the motorway is then achieved by 'balancing' the delays at each of the upstream ramps. On several occasions when the ramp signalling was switched off after significant flow breakdown had occurred, the redistribution of delays was observably obvious – with ramp traffic near the bottleneck getting fairly easy access, and traffic at the tail of the queue coming nearly to a standstill and suffering severe delays. This effect had been predicted by the micro-simulation carried out during the design phase of the project, and one of the resultant aims of the ramp signalling was to 'share' delays equitably.

Northwestern Motorway

Unlike the inner section of the Southern Motorway, the Northwestern Motorway is heavily directional at peak times. Consequently, ramp signalling is only likely to be required to operate in the peak direction in each peak period. Initial traffic modelling showed that there would be a major benefit from ramp signalling, even if the signalling was not able to relieve congestion, through the more equitable sharing of delays along the route. Without ramp signalling, the outer sections suffered severe congestion with the inner sections having minimal congestion. With the ramp signalling now installed, the travel speeds along the motorway are consistent over the whole length. Consequently, users of only the outer section obtained reasonable travel conditions with minimal impact on those joining the motorway at the inner ramps.

Given that the operation of the ramp signalling was not set up to avoid mainline congestion, then the locations that were expected to show significant safety and operational benefits were:

- Newton Road outbound – due to moderating platooning and reducing the period of flow breakdown on this heavily used ramp (up to 1400 vph);
- St Lukes Road outbound – due to moderating platooning effects and reducing the period of flow breakdown;
- Patiki Road outbound - due to reducing platooning effects and the period of flow breakdown;
- Lincoln Road, Te Atatu Road and Great North Road inbound - due to reducing the period of flow breakdown, shifting demand to HOV bypass lanes of the ramp signals, and increasing car occupancy;
- Royal Road inbound – due to moderating platooning effects and reducing the period of flow breakdown.

Northern Motorway

The Northern Motorway is also heavily directional at peak times. Ramp signalling is thus mostly

likely to be required to operate only in the peak direction in each peak period. The directionality of the peak period is reflected in the use of the moveable lane barrier on the Auckland Harbour Bridge to accommodate tidal flows.

In the AM peak, there was extensive flow breakdown outbound (anti-peak) generated from the Curran Street on-ramp. Ramp signalling was commissioned there at about the same time as the Central Motorway Junction and Wellington Street (outbound) ramps. This northbound ramp leads on to the southern end of the 8-lane Auckland Harbour Bridge with a short (sub-standard) merge. As an isolated ramp, where operation of ramp signalling would not adversely impact on other ramps, it was an ideal ramp for isolated metering. Its impact has been extremely positive.

To the north, on the Northern Motorway it is virtually impossible to isolate the operational changes due to ramp signalling, as there were significant capacity changes implemented in conjunction with the ramp signalling.

SELECTION OF EVALUATION SITES AND SECTIONS

Selection of Crash Evaluation Sites and Sections

For selection for crash analysis, sites or sections had to have sufficient data to be able to show a statistically significant change in crash history. Each also had to have a reasonable probability that the changes would be related to the implementation of ramp signalling and not capacity improvements. The sections with major capacity improvement works on each motorway, discussed in preceding subsections, have not been included in this analysis due to the interaction of effects. Each of the locations is shown on **Figure 2**.

Northern Motorway and Southern Motorway sites evaluated were:

- Southbound - Hobson to Gillies, St Marks to Market, Greenlane, Ellerslie-Panmure Highway, Mt Wellington and Takanini
- Northbound - Curran Street, Gillies, Greenlane, Ellerslie-Panmure Highway, SEART, Mt Wellington, and Papakura

Nearly all Northwestern Motorway sites were evaluated:

- Westbound – Newton, St Lukes, Patiki, Te Atatu and Lincoln
- Eastbound – Royal, Lincoln, Te Atatu, Rosebank, Great North and St Lukes

Selection of Operational Evaluation Sites and Sections

For selection for operational analysis, sites or sections had to have suitable speed and flow data. This was only historically available using the incident management system (ATTOMS) sites. Each also had to have a reasonable probability that the changes would be related to the implementation of ramp signalling and not capacity improvements. The sections with major capacity improvement works on each motorway, discussed in preceding subsections, have not been included in this analysis due to the interaction of effects.

Sites evaluated (travel direction in brackets) were:

- Northern Motorway/Southern Motorway - Curran St (N), Symonds (S), Gillies Avenue On (N), Gillies Avenue Off (S), Greenlane (N), Mt Wellington (N), Takanini (S), and Papakura (N)
- Northwestern Motorway - St Lukes, Great North, and Te Atatu (E)

BEFORE & AFTER SPEED & FLOW CONDITIONS

Approach to Presentation of Conditions

Speed and flow rate (volume) data is available at a restricted number of sites on each of the motorways that have had ramp signalling installed. These sites are part of the original ATTOMS incident management system that is capable of providing suitable before and after data to test the operational impacts of the ramp signalling installation. Unfortunately, due to a range of factors, not all sites were operational during both before and after periods, so the number and location of data are necessarily limited.

The data used was for March of each year, and was restricted to Tuesday to Thursday to eliminate effects of weekend traffic – typically Monday mornings and Friday evenings have quite different traffic patterns along each route. For each “year” data, the flows and speeds were averaged over up to five weeks (15 days of data) where available. Since the data is ‘averaged’ the graph shapes, particularly for ‘speed’ are not typically the same as for an individual day. Similarly the average for the month is a different shape to a weekly average.

Figure 3 shows the aggregation of these 5 weeks of data - the 2007 lines in the graphic. The gentle flow recovery is the arithmetic outcome of generally faster recoveries – but ones that occur at different times of the peak.

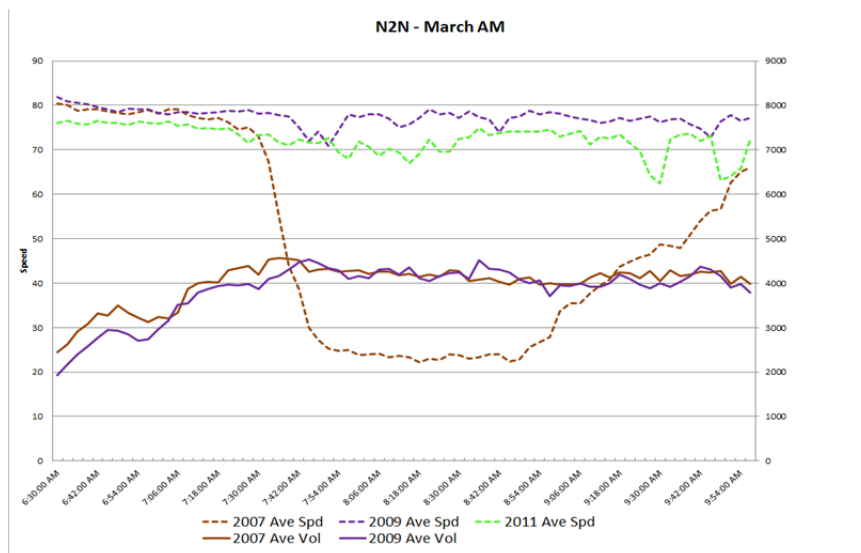


Figure 3 - Monthly Before and After Speed and Flow Data at Curran Street

The Speed v Flow graphs were generated from the data. The “before” data is typically 2007 and the “after” is typically 2009. Where data was not available for those years, the nearest available data was used. Where appropriate, comments relating to each graph are made to explain some of the outcomes. The graphs, and the data behind them, allow an assessment of the period of flow breakdown and also any changes in throughput rates before and after the introduction of ramp signalling.

Discussion of Before and After Speed v Flow Conditions

Southern Motorway Southbound

At Symonds Street, there was a significant reduction in the period and severity of flow breakdown and also an increase in throughput during the period of previous flow breakdown. The flow breakdown is created at the Gillies Avenue bottleneck, and the Symonds Street conditions reflect the extent of queuing from that flow.

The lane drop immediately beyond the Gillies Avenue exit was the major southbound bottleneck immediately before and after the introduction of ramp signalling. The AM peak shows a shorter period of flow breakdown, and higher speeds and throughput in the after situation. It is similar in the PM peak with flow breakdown in the before period occurring well before the start of the data analysis. (Anecdotally, flow breakdown occurred through most of the inter-peak period in the before situation, but the inter-peak problem was largely resolved by the ramp signals at Khyber Pass Road Road).

Southern Motorway Northbound

At Mt Wellington the before and after conditions were effectively identical with a very gradual drop in speeds, following the peak flow of about 4,000 vph (close to the capacity of the 2-lane carriageway through the interchange), indicates that this location is not a critical bottleneck, but is well upstream of the critical bottleneck. Also, the recovery slope indicates that the data is made up from many days and that the flow breakdown occurred at different times. Mt Wellington is one of the few sites to show a worsening of conditions in the after period, with a drop in speed in the PM peak, associated with increased throughput.

At the Greenlane interchange, the AM peak period flow breakdown has occurred slightly earlier, with recovery also slightly earlier. Minimum speeds at the height of the peak have improved from about 30 km/h to 40 km/h. The PM peak shows a similar pattern – but with significantly worse situation mid-afternoon, significantly better speeds at the height of the peak, and recovery occurring about a quarter of an hour earlier.

At Gillies Avenue, the AM peak conditions had slightly better speeds and throughput. The maximum throughputs occur until around 7:45 am before the effects of significant flow breakdown north of Greenlane occur as on-ramp traffic there increases and flow breakdown occurs near Market Road – reducing critical bottleneck throughput. In the before-period, on a daily basis flows and speeds tended to vary rapidly during short periods – indicative of “stop-start” conditions. Conditions were more stable during the after-period.

In the PM peak, substantial improvements occurred. This has occurred despite generally worse conditions downstream.

Possibly the greatest impact from ramp signalling occurred at the Curran Street on-ramp in the AM peak as is seen in **Figure 3**. Flow breakdown in the before period was severe with average speeds at about 25 km/h in an 80 km/h speed limit zone. In the immediate after period speeds remained close to the speed limit. Two years later (green dotted line) there was a minor drop in speeds. In the PM peak, there was a slight improvement in speeds, a slight increase in throughput, and a shorter period with the lowest speeds.

OPERATIONAL PERFORMANCE

Basis of Analysis

Each of the available site graphs was assessed visually to estimate the start and end of flow breakdown in the before and after periods. These were then referenced into the spreadsheet containing the data, and the start and end speeds matched (where possible).

Definitions

The following definitions have been used in this section of the report:

- Before average speed (km/h) – this is the average speed calculated from the spreadsheet data for the flow breakdown period;

- Before time extent of flow breakdown (h) – occurring within the peak periods of 6:30 am to 10:00 am and 3:30 pm to 7:00 pm;
- Recovery distance (m) – estimated by the author based on the difference in before and after speeds;
- Average before flow rate (vph) - calculated from the spreadsheet data during the flow breakdown period;
- Estimated upstream Q length (m) – the distance between the on-ramp and the back of the rolling queue of vehicles slowed by the flow breakdown at the on-ramp - estimated by the author based on field experience and in consultation with system operators in Auckland;
- After average speed (km/h) - calculated over the same time period as the before one;
- Recovery delay/vehicle (s) – the calculated delay while accelerating from the average before speed to the average after speed over the recovery distance – based on Melbourne data, speeds downstream of flow breakdown increase on average about 20 km/h for each 500 m;
- Q delay/vehicle (s) - the travel time difference when travelling at the average before speed compared to the average after speed over the queue distance;
- total delay/vehicle (s) – sum of recovery delay and Q delay;
- Daily delay reduction (h) – the total delay reduction per vehicle multiplied by the number of vehicles experiencing the delay during before period;
- Annual delay reduction (h) – daily delay reduction multiplied by 250.

Analysis

Delay Benefits Calculations

Benefits due to reduced delays can be estimated knowing the before and after speeds, the length of upstream queues, and the flow throughput. Depending on the before speeds estimates can also be made of the likely distances over which flow recovery occurs – i.e. returning from queuing speed to nominal free-flow speed. **Table 1** sets out the calculation sheet for estimating savings in delay.

Measures for Recovery & Queue Delay	AM Period	PM Period
Before average speed (km/h)	36	63
Before period of flow breakdown (h)	2.5	2.0
Recovery distance (m)	800	800
Average before flow rate (vph)	4107	6800
Estimated upstream Q length (m)	1000	1000
After average speed (km/h)	77	67
Recovery delay/veh (s)	13.6	1.3
Q delay/veh (s)	53.2	3.4
Total delay/veh (s)	66.8	4.7
Daily delay reduction (hr)	194.4	17.9
Annual delay reduction (hr)	48610	4470

Table 1 - Before & After Delay Calculator Example

Productivity Benefits Calculations

“Productivity” of the motorway has been measured in terms of increased throughput at available ATTOMS stations. The throughputs used are measured in **Table 2** and **Table 3**. For the Southern Motorway and Curran Street, the increased throughput averages 7.3% (AM) / 8.7% (PM) in the / peak periods southbound, and 1.0%/6% northbound. For the Northwestern Motorway, the increases are 12.7% (AM) eastbound, and 14.7% (PM) peak westbound.

Operational Outcomes

Table 2 sets out operational outcomes for the Southern Motorway and the Curran Street ramp on the Northern Motorway. It can be seen in Table 2 that southbound the average speeds have increased by about 14 km/h across both peaks, combined with significant increases in flow rates. Northbound the effects have not been as profound, with a 8 km/h average increase. Mt Wellington northbound is the only site with significant speed reduction, but there is a compensating significant increase in flow rate (10.5%). Annual delay savings of 150,000 hours have been achieved at the two southbound sites, with 100,000 hours at the four northbound sites. The group of sites studied have generated annual travel time savings of around \$5 m.

Table 3 provides similar data for the three available locations on the Northwestern Motorway. Eastbound the average speeds have also increased by about 14 km/h inbound in the AM peak, combined with significant increases in flow rates of about 12.7%. Westbound the effects are less, with a 5 km/h average speed increase, but with even greater increases in flow rates of about 14.7%. Annual delay savings of around 100,000 hours have been achieved at the three sites, which have generated annual travel time savings of around \$2 m.

Site	Peak Period	Duration (h)		Ave Speed		Ave flow		Delay savings	
		Before	After	Before	After	Before	After	/vehicle (s)	/yr (h)
Southbound									
Symonds	AM	1.75	1.0	42	56	4960	5450	21.4	26980
	PM	3.5	2.5	30	52	3730	4200	50.8	38280
Gillies Avenue Off	AM	2.75	2.0	48	56	5840	6140	21	26880
	PM	3.75	3.25	38	49	5475	5810	41	58170
Average (Total)		2.9	2.2	39.5	53.2	(20005)	(21600)	(134.2)	(150310)
Northbound									
Mt Wellington	AM	3.5	3.5	48	48	2890	2930	0	0
	PM	3.5	3.25	62	57	2360	2610	-7.2	-4380
Greenlane (N)	AM	3.5	3.25	49	52	4770	4800	10.1	10120
	PM	3.5	3.25	43	47	4100	4050	17	15710
Gillies Avenue On	AM	1.5	0	67	71	5840	6000	3.6	2250
	PM	3.5	3.25	44	57	4610	5350	34.5	25630
Curran St (N)	AM	2.5	0	36	77	4110	4140	67	48610
	PM	2.0	1.0	63	67	6800	6935	4.7	4470
Average (Total)		2.85	2.2	51.5	59.5	(35560)	(36815)	(161.7)	(102410)

Table 2 - Southern Motorway– Operating Conditions – Before & After

Site	Peak Period	Duration (h)		Ave Speed		Ave flow		Delay savings	
		Before	After	Before	After	Before	After	/vehicle (s)	/yr (h)
Eastbound									
Te Atatu	AM	3.0	2.75	51	58	3660	4250	21	15330
Great North	AM	2.75	2.0	47	69	3620	4040	58.7	40790
St Lukes	AM	3.25	2.5	43	55	4170	4610	44.5	35580
Average (Total)		3	2.4	47	60.7	(11450)	(12900)	(124.2)	(91700)
Westbound									
St Lukes	PM	2.5	2.25	57	57	3780	4190	0	0
Great North	PM	2.5	2.25	53	65	2840	3550	18.8	11500
Te Atatu	PM	3.5	3.25	66	68	2830	3100	3	1270
Average (Total)	PM	2.8	2.6	58.7	63.3	(9450)	(10840)	(21.8)	(12770)

Table 3 - Northwestern Motorway – Operating Conditions – Before & After

Whole of Network Operational Benefits

As data was available for only some of the motorway segments impacted by ramp signalling, only a proportion of the directly attributable operational benefits have been able to be estimated. The total operational benefits across the network are likely to be about double those estimated in **Tables 2 and 3**.

ANALYSIS OF CRASHES

Analysis of All-severities of Crashes

Before and After (B&A) analyses have been undertaken on the selected sites on the basis of data extracted from material presented in the New Zealand Transport Agency's AMA Crash Reduction Study – Motorways (2011) which assesses data from 2005-2010. The data for that study is extracted from the NZ National Road Crash Data Base of all recorded crashes in NZ. Casualty crashes were not able to be readily isolated, but are known to be a small proportion of all crashes. The data in the Crash Reduction Study report was disaggregated into 4 categories – “lane changing” (LC), “loss-of-control” (LOC), “Rear-end” (RE) and “other”. The data was presented in tabular format for each 100 m long segment of the motorways. There were few crashes in “Other” category, and they have been left out of this analysis. With most ramp signal works on the Southern Motorway installed during 2008, the before and after periods were 2005-2007 (3 years) and 2009-2010 (2 years) respectively. **Table 4** provides the Southern Motorway analysis.

The Mt Wellington to Market section of SH1 northbound still suffers significant congestion in both AM and PM peaks, and hence one would not expect a substantial reduction in crashes, although 11% reduction was achieved.

Despite more than a 50% overall reduction in northbound RE crashes in the weaving area between Gillies Avenue and Khyber Pass Road (a sub-section of Gillies Avenue to SH16), in the after period, 37% occurred outside of the ramp signalling operating times, while 31% occurred at weekends compared to just 12% (of a much larger number) on weekends in the before-period. This suggests that the ramp signalling has been very successful in addressing safety in the weaving area, and that ramp signalling should be operated on weekends as well as on weekdays.

Table 5 provides the comparative data for the Northwestern Motorway. The outcomes are consistent with the Twin Cities Study (2002).

Site	All Crash Severities										
	Before					After					Change
	LC	LOC	RE	Tot	/yr	LC	LOC	RE	Tot	/yr	
Southbound											
Hobson to Gillies	89	26	154	269	89.7	41	15	62	118	59	-34%
St Marks to Market	23	4	63	90	30	3	6	23	32	16	-47%
Greenlane	9	11	32	52	17.3	8	4	19	31	15.5	-10%
Ellerslie-Panmure Hwy	15	4	18	37	12.3	4	6	9	19	9.5	-23%
Mt Wellington	14	6	45	65	21.7	8	2	18	28	14	-35%
Takanini	5	6	9	20	6.7	1	1	4	6	3	-55%
Totals				533	178				234	117	-34%
Northbound											
Papakura	4	8	25	37	12.3	4	4	8	16	8	-26%
Takanini	4	1	4	9	3	4	1	1	6	3	-0%
Hill	2	5	8	15	5	2	3	5	10	5	-0%
Te Irirangi	6	4	20	30	10	4	8	8	20	10	-0%
East Tamaki	8	4	5	17	5.7	1	5	5	11	5.5	-4%
Mt Wellington to Market	72	31	341	444	146	55	17	187	259	129.5	-11%
Gillies to SH16W	65	14	126	205	68.3	32	10	77	119	59.5	-13%
Curran Street	51	26	131	208	69.3	26	11	66	103	51.5	-26%
Totals				965	322				544	272	-16%

Table 4 - Southern Motorway & Curran Street – All Crash Severities – Before & After

Site	All Crash Severities										
	Before					After					Change
	LC	LOC	RE	Tot	/yr	LC	LOC	RE	Tot	/yr	
Westbound											
Newton	6	18	29	53	17.7	7	6	8	21	10.5	-41%
St Lukes	9	7	39	55	18.7	4	6	21	31	15.5	-17%
Patiki	9	10	24	43	14.3	2	5	8	15	7.5	-48%
Te Atatu	4	3	17	24	8	0	5	7	12	6	-25%
Lincoln	5	13	10	28	9.3	4	5	5	14	7	-25%
Totals				203	67.7				93	46.5	-32%
Eastbound											
Royal	6	6	7	19	6.3	3	4	1	8	4	-37%
Lincoln	11	9	12	32	10.7	7	6	19	32	16	+50%
Te Atatu	8	16	13	37	12.3	6	5	10	21	10.5	-15%
Rosebank	2	7	8	17	5.7	1	1	5	7	3.5	-39%
Great North	10	13	11	34	11.3	1	6	8	15	7.5	-34%
St Lukes	10	7	38	55	18.3	2	2	21	25	12.5	-32%
Totals				194	64.7				108	54	-17%

Table 5 - Northwestern Motorway – All Crash Severities – Before & After

Whole of Network Benefits

As data was available and analysed for most of the motorway segments impacted by ramp signalling, most of the directly attributable crash reductions are recorded in **Table 4** and **Table 5**. These tables should, therefore, indicate the level of safety benefits for the whole network.

RAMP METERING INTENSIVE WEAVES

The Khyber Pass Road to Gillies Avenue section was a critical bottleneck with flow breakdown occurring due to the extremely high weaving flows – about 1900 vph entering, and 1300 vph exiting downstream (northbound PM peak) and the opposite in the southbound AM peak– with a weaving distance of about 380 m. This weaving flow breakdown occurred often from mid-morning, so the benefits estimated here are a significant underestimated. The flow breakdown that did occur in the PM peak was almost always associated with a centre lane queue extending back from flow breakdown at the congested SH1/SH16 downstream system ramp or the Wellington Street on-ramp.

The ramp signals on the Gillies Avenue on-ramp handled peak flow rates of up to 1950 vph with 2-lane storage at the signals merging to a single lane entry to an “added lane” on the mainline that has an auxiliary lane commencing just upstream of the ramp. This allows a relatively low weaving density per lane, with the auxiliary lane containing mostly only traffic heading for the off-ramp.

Without the ramp metering, there was a continuous line of slow-moving closely spaced vehicles entering. The ramp signal operated on a cycle time of 3.9 s to 4.2 s which creates gaps of 10-20 m between ramp vehicle pairs at speeds of around 60 km/h – enough to allow off-ramp traffic to find weaving gaps, and virtually eliminating flow breakdown. Unlike typical ramp metering operation where ramp traffic flow rates are maximised to minimise ramp delays, the weaving on-ramp flows entered at the slowest rate to maximise gaps - rather than using the fastest rate. As on-ramp queues built up, the metering rate was increased slightly to reduce the queue. This mode of operation maximises the physical gaps for the weaving traffic heading for the downstream off-ramp.

CONCLUSIONS

This study investigated the safety and operational outcomes of ramp signalling introduced onto the Auckland motorway system between 2007 and 2010. Operational before and after data was limited to incident management system sites, and readily accessible crash data was limited to all (casualty and property damage) crashes. Data was not assessed for sites where major capacity improvements were effected, where there was no flow breakdown in the before periods, or where the ramp signalling was operated in a manner that did not aim to improve traffic flow.

The findings from the study have been very positive in terms of operational and safety performance:

- Productivity (increased throughput):
 - Southern Motorway and Curran Street, the increased throughput averages 7.3%/8.7% in the AM/PM peak periods southbound, and 1.0%/6.0% northbound.
 - Northwestern Motorway, the increases are 12.7% (AM) eastbound, and 14.7% (PM) peak westbound.
- Average speeds increases:
 - Southern Motorway southbound - 14 km/h across both peaks combined with significant increases in flow rates.

- Southern Motorway to Curran Street - northbound - 8 km/h average increase.
 - Northwestern Motorway - 14 km/h inbound in the AM peak, combined with significant increases in flow rates of about 12.7%.
 - Northwestern Motorway - 5 km/h average speed increase outbound, but with even greater increases in flow rates of about 14.7%.
- Annual delay savings:
 - Southern Motorway/Curran Street - 150,000 hours at the two southbound sites, with 100,000 hours at the four northbound sites. The group of sites studied have generated annual travel time savings of around \$5 m.
 - Northwestern Motorway - 100,000 hours at the three sites, which have generated annual travel time savings of around \$2 m.
 - Crash reductions:
 - Southern Motorway – 34% outbound and 17% inbound;
 - Northwestern Motorway – 32% outbound and 17% inbound.

The most significant outcome was using ramp metering to eliminate flow breakdown in a short but intensive weaving area - 3,300 vph weaving flow rate achieved in a 390 m weave length.

The ramp signalling program implementation in Auckland has been very successful in achieving its goals of reduced travel times, increased throughput at critical bottlenecks, and crash reductions – as indicated by available data, and where the implementation has been designed to achieve those goals.

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