New Zealand’s Easy Merge Ramp Signal (Ramp Metering) Trial

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Ramp metering is a traffic management tool used extensively overseas to reduce congestion resulting from on ramp traffic merging with motorway or freeway traffic. Ramp signals regulate the flow of traffic on on-ramps to prevent the discharge of dense platoons of traffic into the nearside traffic lane which is a principal cause of flow breakdown and delay on motorways.

This paper reports on the trial of the Easy Merge Ramp Signal (ramp metering) that commenced on 1 March 2004 at the Mahunga Drive northbound on-ramp on SH20. This is one of the first ramp metering trials in New Zealand.

Evaluation of this trial concluded that ramp metering has successfully improved the traffic performance of the road network within the vicinity of the ramp metering site. Traffic throughput (network wide) and travel speed (SH 20) were significantly increased. It is already evident that the success of this trial has introduced ramp metering as a very useful traffic management tool in New Zealand. Transit New Zealand has prioritised Travel Demand Management projects in Auckland as its top three national projects. Ramp metering is seen as one of the main traffic management tools available to achieve Travel Demand Management outcomes.

Ramp metering has been widely used, mainly in Europe, USA and Australia, as a traffic management tool to reduce congestion resulting from on-ramp traffic merging with motorway traffic. Ramp signals on the on-ramp regulate the flow of traffic to prevent the discharge of dense platoons of traffic into the nearside traffic lane which is a principal cause of flow breakdown and delay on motorway under peak motorway flow conditions. The signals operate a short cycle allowing one vehicle per lane to join the motorway traffic at each green period **(see Figure** 1**)**. The associated duration of the red period within the signal cycle varies depending on the density of traffic in the adjacent motorway lanes. As the flow on the motorway becomes denser, the red period increases, thus reducing the incoming flow rate from the on ramp.

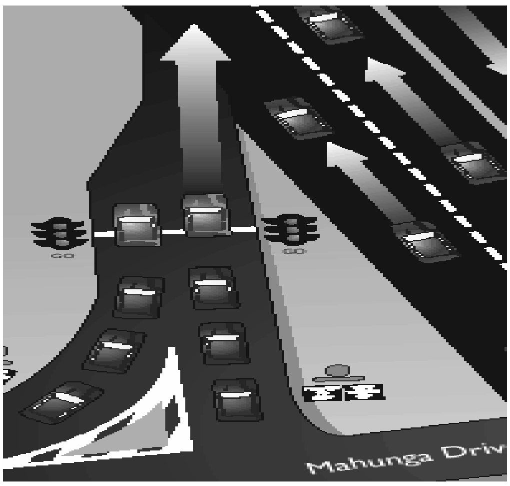

Figure 1: Ramp Metering illustration

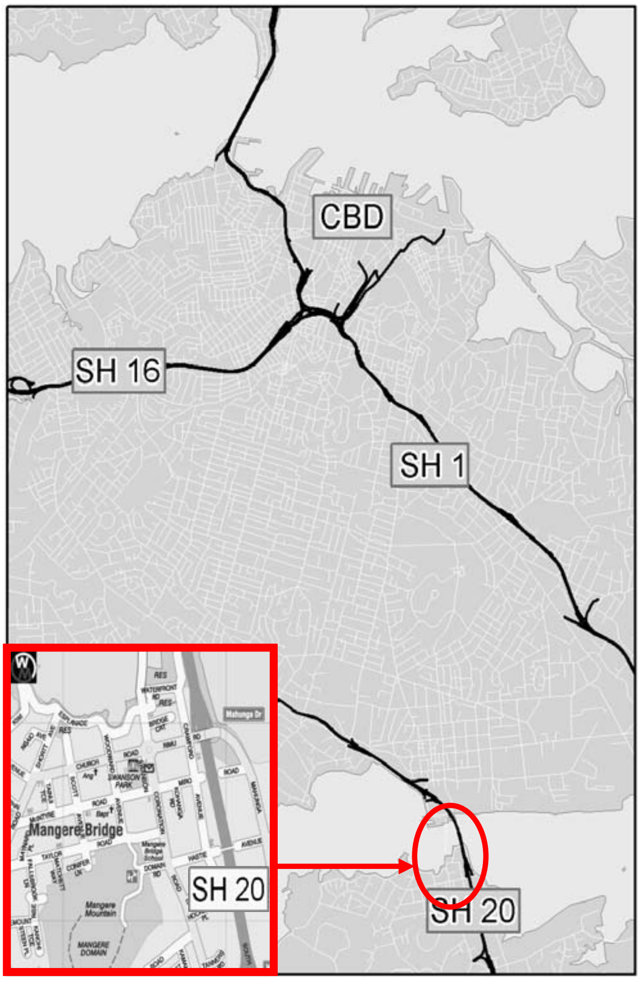

Figure 2: Location Map of Trial Site

1 Trial Site Description

The Mahunga Drive on-ramp is located on the South-western Motorway (SH20), approximately 10km south of Auckland's Central Business District **(see Figure 2)**. The South-western motorway is a four-lane motorway linking Manukau City and Auckland's International Airport with arterial roads north of Manukau Harbour. In future, it is anticipated that the SH20 corridor will provide a continuous motorway connection between the Southern Motorway (SH1) at Manukau City, and the North-western Motorway (SH16) near Waterview.

2 System Design

This project was undertaken as a prototype for future installations of ramp meters across the motorway, and to assist in development of the geometric standards and operating protocols for ramp metering systems in New Zealand.

The design includes the geometry of the approaching lanes, ramp metering system (hardware including traffic signage and software) and operations sequencing/ protocols for the ramp metering system.

3 Geometric Design

The limit line of the ramp meter signal is located by balancing:

- The required distance for the merge from two lanes to one lane on the ramp;
- The required distance for accelerating to merge with the motorway traffic; and,
- The need for storage.

For the purpose of this trial, the limit lines were placed such that the ramp traffic can sufficiently accelerate to approximately 80kph before merging with the motorway traffic, thus covering the "worst-case" scenario whilst the ramp meter signals are on. When the ramp meter signals are off, the whole ramp is available for acceleration to the motorway free-flow speed. Approximately 120 metres of storage in each lane on the on- ramp was achieved; this is consistent with the VicRoads guideline for storage length where a minimum of 100m is recommended for each lane of a two lane metered on-ramp.

Ramp metering can operate with either single or dual lanes, and, if appropriate, a separate additional lane for priority vehicles. The capacity of a metered ramp is dependent on the cycle time. At the Mahunga Drive on-ramp, cycle times range between 5.5 sec and 12 sec. This corresponds with flow rates of 1,300vph to 600vph for the dual lane ramp. A single metered lane would only discharge 650 to 300vph at similar cycle times unless more than one vehicle was permitted to discharge in each cycle.

Traffic demands on the Mahunga on-ramp exceeded flow rates of 800vph therefore a dual lane ramp layout was considered necessary. At this trial site, the existing available ramp width allowed two 3.2m wide lanes to be provided, with 0.3m lateral clearance to the barrier.

A new geometric standard for installation of ramp metering systems is currently being finalised by Transit New Zealand.

4 Ramp Metering System (Hardware)

The ramp metering system involved a series of three separate displays. Display A **(see Figure 13)** consists of two single-column, 3-aspect traffic signals separated by a regulatory traffic sign that displays the words "One Vehicle Per Green Each Lane". The purpose of this regulatory sign is to inform drivers that only one vehicle is permitted to discharge per lane when the green signal is displayed. This sign also enables enforcement of the ramp signals.

Figure 3: Ramp Meter Display A

Display B **(see Figure 4)** is a Variable Message Sign (VMS) with two yellow aspects (one at the top and the other at the bottom of the VMS). This sign displays either the words 'Ramp Signal On' or a blank message, and is located on the adjoining arterial road. The purpose of this display is to inform drivers that the ramp meter is operating and hence giving them the option of avoiding entering the ramp.

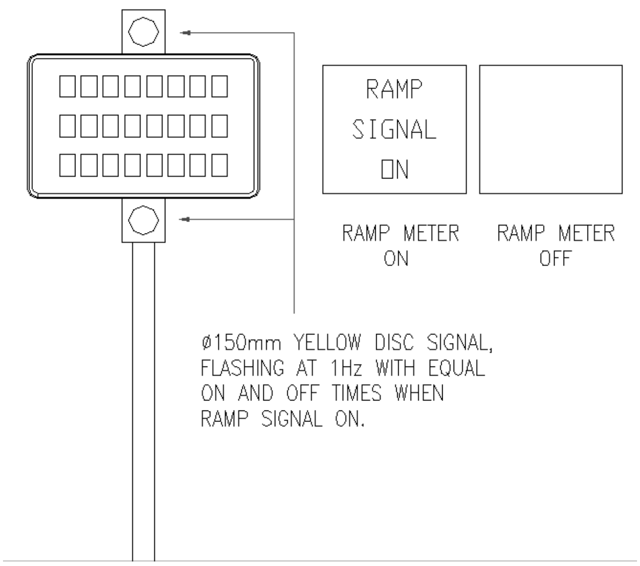

Figure 4: Ramp Meter Display B

Display C **(see Figure 5)** is the standard PW-3 sign and a VMS. This VMS displays either the words 'Prepare to Stop' or 'Ramp Signal Off'. Display C is located at the adjoining arterial road. These signs are used to warn motorists of the impending signals and the state in which they are in.

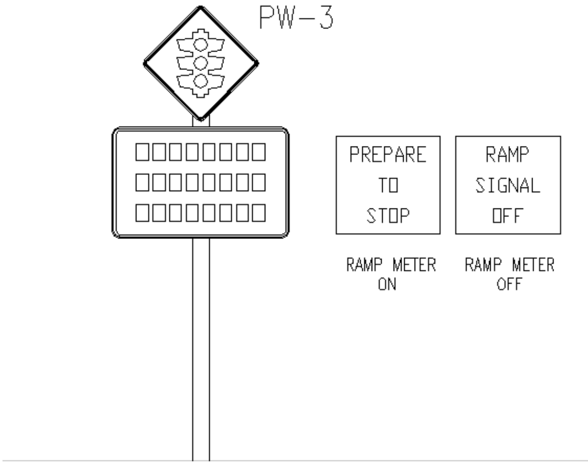

Figure 5: Ramp Meter Display C

5 Ramp Metering System (Software)

The SCATS Ramp Metering System (SRMS) chosen for this trial was an "off the shelf" product developed by the Roads and Traffic Authority, NSW (RTA). This software requires detector loops for its operation **(see Figure 6)**

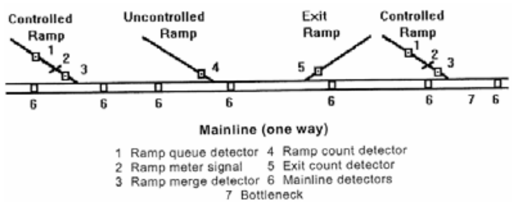

Figure 6: Detector Loop Details

As this trial only involves one ramp meter, mainline detectors at two sites, two ramp queue detectors, a ramp merge detector and a ramp count detector were installed.

The software operation of SRMS can be summarised by the following:

1 The ramp meter is triggered on or off by two variables in the algorithm ('a' and 'b'). When 'a' and 'b' exceed a preset value individually or the combination of 'a' and 'b' exceed the preset combination range, the meter switches on. When 'a' and 'b' drop below a preset value the meter switches off.

2 ‘a’ is a lane occupancy factor and ‘b’ is a function of ‘N’ and ‘g’, where ‘g’ is a function of the ramp queue and ‘N’ is the flow balancing factor.
3 The red period is variable and is influenced by ‘a’ and ‘b’.
4 The yellow and green period is fixed at 0.7and 1.3 sec respectively for each cycle.

6 Ramp Metering Operation Protocols

As ramp metering systems were not a traffic control device provided for in the Traffic Regulations (1976), the trial required a Gazette notice for its operation. The associated ramp metering operation protocols were developed and defined within the Gazette notice as follows:

When the ramp signal (ramp meter) is in the ‘off’ state:

1 In display A, none of the traffic signal aspects may be illuminated and the variable traffic sign must read ‘Ramp Signal Off’; and
2 In display B, the variable traffic sign must be blank; and
3 In display C, the variable traffic sign must read ‘Ramp Signal Off’.

When the ramp signal (ramp meter) is operational:

1 In display A, the traffic signals must operate in the following sequence:

   (a) the yellow disc signals, must flash at approximately one Hertz, for a period of at least 10 seconds followed by:

   (b) the red disc signals followed by:

   (c) the green disc signals displayed for a maximum period of 1.3 seconds followed by:

   (d) the yellow disc signals displayed for a maximum period of 0.7 seconds followed by:

      (i) the red disc signals; or

      (ii) the red disc signals for at least 3 seconds followed by the ramp signals moving to the ‘off’ state

2 In display B, the variable traffic sign must read ‘Ramp Signal On’ and the yellow disc signals must flash alternately;
3 In display C, the variable traffic sign must read ‘Prepare to Stop’.

The Land Transport Rule – Traffic Control Devices 2004 now includes a section for the use of Ramp Signals. This new section is based on the operational protocols developed for the Mahunga Drive ramp signal trial.

7 Ramp Metering Trial Objectives

The primary objective of the Easy Merge Ramp Signal at Mahunga Drive was to improve the throughput on the motorway by preventing flow breakdown from occurring at the on-ramp merge area. The secondary objective was to redistribute the approach traffic flows in the adjoining network such that all adjacent on-ramps were better utilised, i.e. reduce “rat running”.

8 Performance Indicators

The following performance indicators were adopted for the ramp metering trial:

- Increasing throughput on SH20 upstream of Mahunga Drive on-ramp;
- Increasing capacity at the merge area of the Mahunga on-ramp and SH20;
- Improving speeds through the merge area;
- Improving trip reliability;
- Improving traffic flow conditions through reduced frequency and severity of flow breakdown;
- Increasing the use of adjacent ramps
- Reducing “rat running” through Mangere Bridge township; and
- Improving safety.

The performance of the network before and after the commissioning of the ramp meter was assessed. Generally, the data was examined for the month before and after commissioning. Given that an initial “shock” of the network was likely (and confirmed as the results indicated), a further evaluation was conducted to analyse the local area effects, six months after the system was activated and the network had stabilised. Motorway speed and flow comparisons were derived by comparing the corresponding months in 2003 and 2004.

Therefore the benefits of ramp metering to the traffic conditions on the motorway will be understated because an equivalent scenario without ramp metering has not been derived.

9 Motorway Performance

The operation of the motorway was assessed against each performance indicator. Fifteen-minute profiles were developed to analyse speed and flow on SH20 and the on-ramp. The data presented in the graphs is from October, six months after commissioning the ramp meter. Speed flow relationships in conjunction with CCTV footage were used to analyse the operation of the motorway, and to assess flow instability and breakdown.

10 Traffic Throughput

The flow profiles (see **Figure 7** and **Figure 8**) through the two years prior to commissioning show a declining performance of SH20 upstream of the Mahunga Drive on-ramp between 2002 and 2003, represented by the marked decreases in throughput volume.

The graphs indicate continuing traffic growth in traffic in the pre-peak period, therefore the decrease in volume shown in the graphs is due to flow breakdown and forced flow rather than a decrease in demand. The operation of the ramp metering system has clearly minimised this condition and contributed to the following:

- Increases in throughput in two lanes prior to the merge area from as low as 3,400vph in 2003 to as high as 4,000vph in the peak hour (3% - 15% increase on pre-metering flow conditions)
- Increase in throughput on SH20 from as low as 2,400vph as high as 3,300vph in the peak hour (9% - 26% increase on pre-metering flow conditions)
- Increase in ratio of SH20 traffic to total traffic over Mangere Bridge from 70-75% on SH20 pre-metering to upwards of 80% on SH20 post-metering.

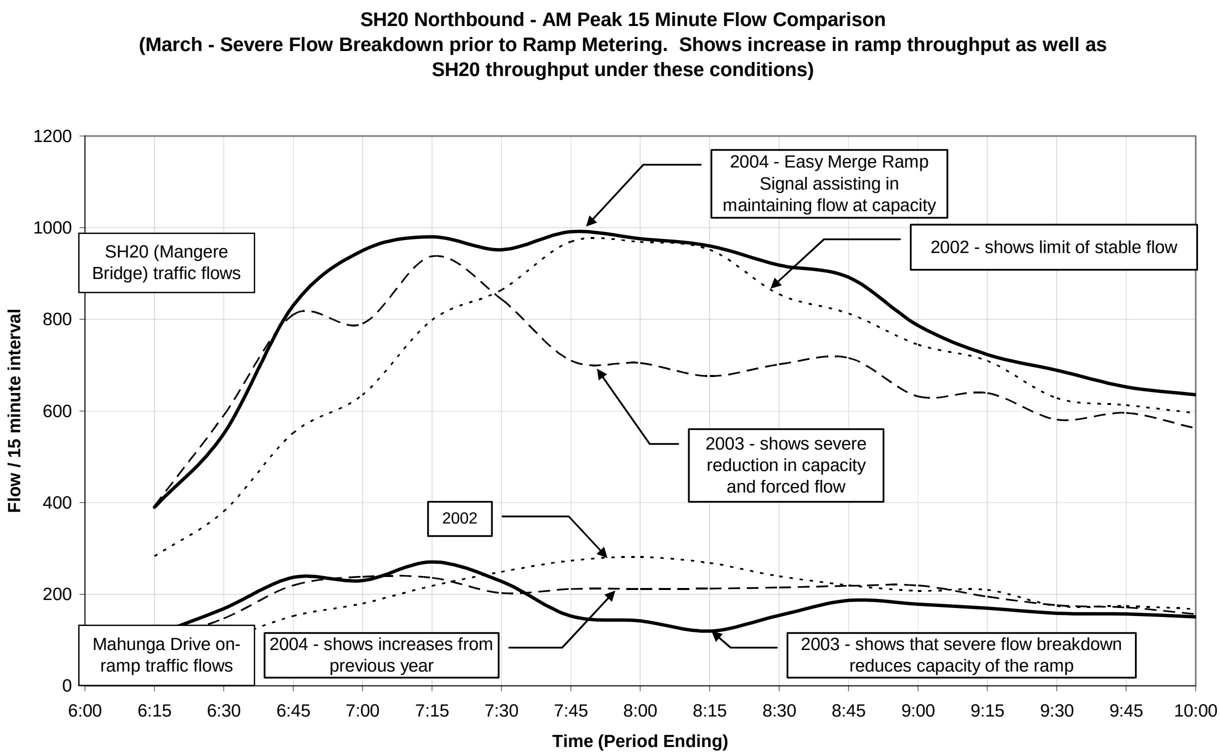

Figure 7: Morning peak period throughput

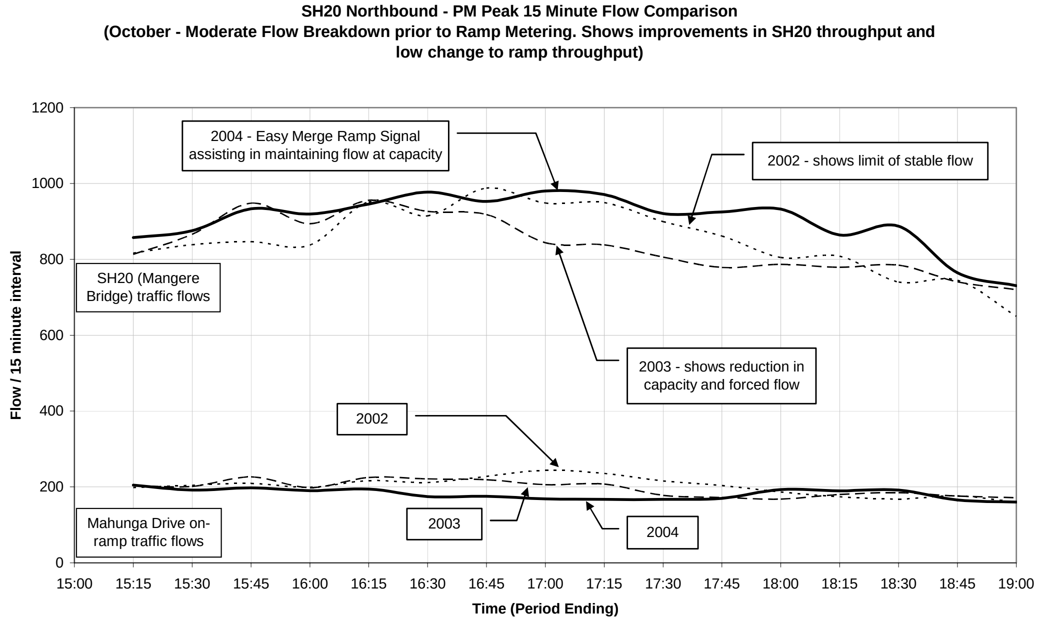

Figure 8: Evening peak period throughput

11 Speed

The speed profiles show a significant decline in speed prior to ramp metering in both the morning and evening peak periods. The morning peak period shows widely varying results, which upon inspection of the data for each individual day indicates high variability in the evening peak traffic conditions.

The ramp metering system has reduced the variability of speed along SH20 especially in the evening peak period. An increase in fifteen minute average speeds from 25 - 35kph to 40 - 50kph were also achieved. This represents an increase in between 5kph and 15kph from the previous year. This reduction in travel speed variability indicates that trip reliability has improved and potentially contributes to reduction of “high-speed rear end” type accidents through the merge area.

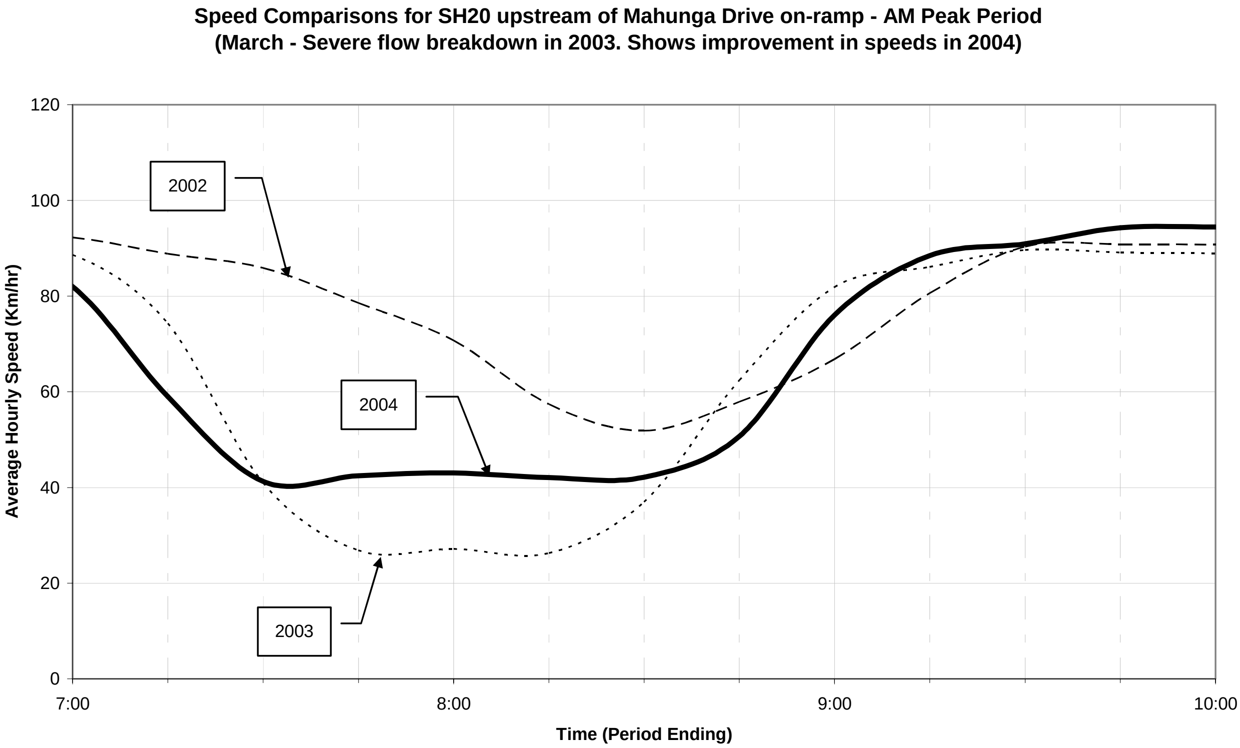

Figure 9: Morning peak period speed profiles

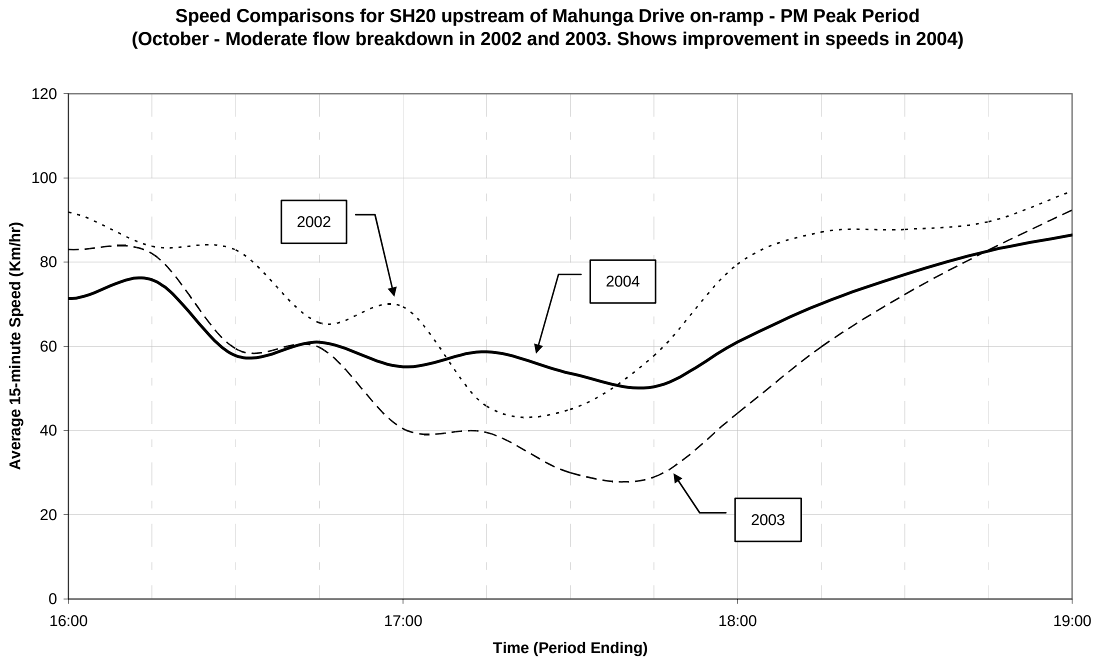

Figure 10: Evening peak period speed profiles

12 Traffic Flow Conditions

The speed flow profiles (**see Figure 11 and Figure 12**) indicate that prior to ramp metering, the onset of flow breakdown was very rapid, as illustrated by the near vertical drop in the curves. The profiles show that ramp metering has both increased throughput and reduced the severity and duration of flow breakdown.

In both the morning and evening peak period, there were only relatively short periods where forced flow conditions occurred after the activation of the ramp metering system. Analysis of the CCTV footage confirmed the improvement in the operation of the merge area with much less instability and improved speeds through the merge area.

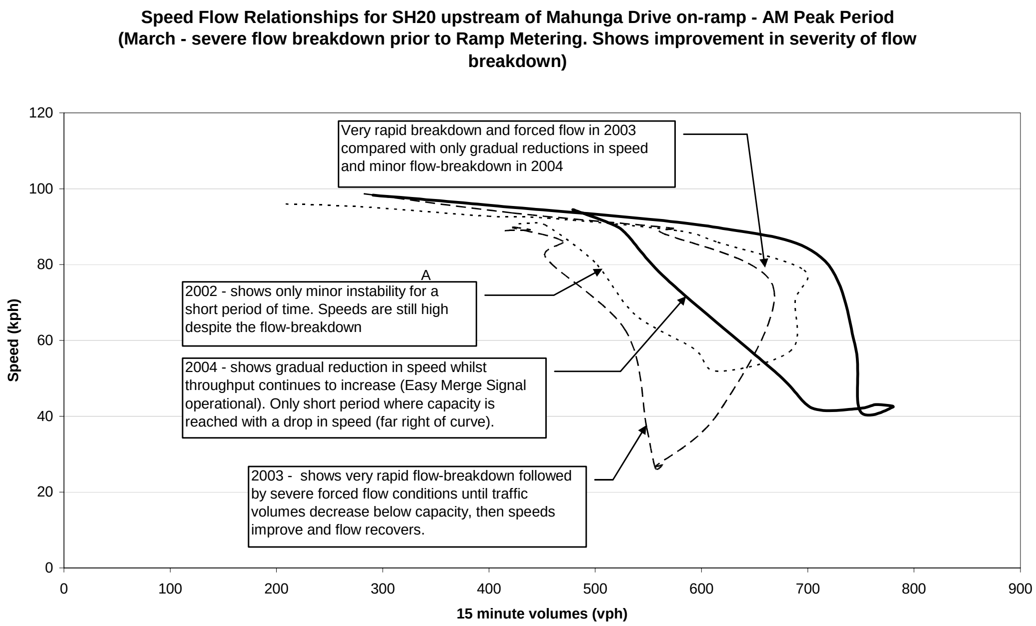

Figure 11: Morning peak period traffic flow conditions

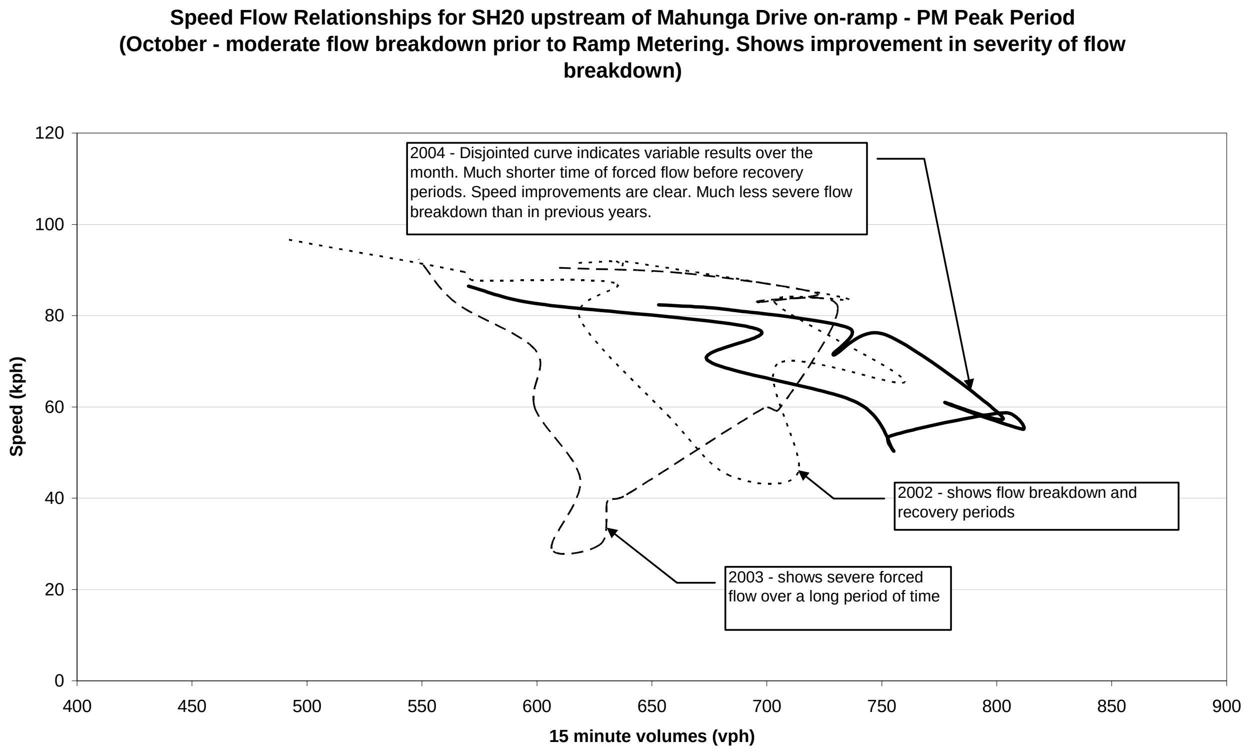

Figure 12: Evening peak period traffic flow conditions

13 Local Road Impacts

The local road impacts were assessed by measuring the queue lengths, measuring the queued journey times, and measuring changes in traffic volumes at the Mahunga Drive on-ramp, and from identifying the proportion of trips generated from Mangere Bridge Township and adjacent industrial area. The on going changes in traffic volumes across the wider area are continuing to be monitored.

14 Queuing

Figure 13 shows the average time on representative workdays (Tuesday, Wednesday and Thursday) that queues extend beyond specific points (not waiting time). The measurements are given in minutes over the two hour period.

In general the amount of time where queuing exists has increased as a result of ramp metering. However, an inspection of the daily data six months of ramp metering shows that the longest queue observed are no worse than they were prior to ramp metering, even though queues exist for a longer period. Inspection of the daily data both prior to ramp metering and after six months of operation shows that the queue lengths are very much dependent on the operation of the motorway. Under normal traffic conditions, traffic queues vary from 400-500 metres in length. As experienced previously, longer queues periodically occur during abnormally heavy conditions.

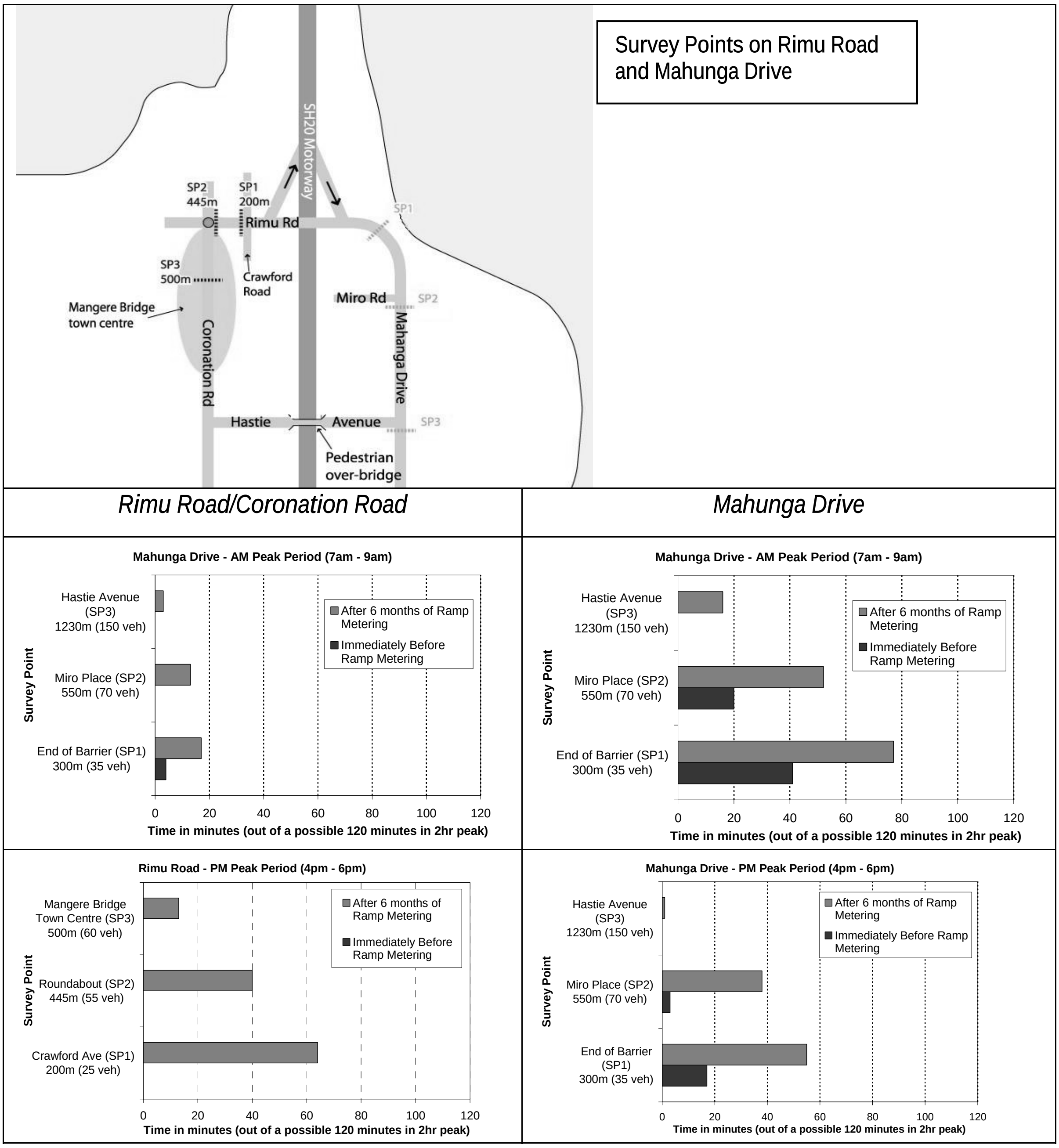

Figure 13: Queuing levels over the two hour peak periods

15 Delay

The queued journey times were recorded after the ramp metering system was commissioned. The table below shows the queuing delay associated with ramp metering after six months operation. The data is presented in terms of a "normal" weekday.

The purpose is to show that, as with the period prior to ramp metering, traffic conditions on the local road network continue to be highly dependent on traffic conditions on the motorway. In simpler terms, when the motorway operates poorly, the queuing and delay on the local road increases regardless of the whether the ramp meter is in operation or not.

Time Period	Rimu Road			Mahunga Drive		
	Length	Max Queued Delay	Range (based on 1 std dev)	Length	Max Queued Delay	Range (based on 1 std dev)
Morning 2hr Period	500 m	9 min	6 – 12 min	300	5 min	4 – 7 min
Evening Peak Period	200m	4 min	3 – 5 min	550	10 min	8 – 13 min

Table 1: Journey Times in queue for "normal" weekdays

16 Use of Adjacent Ramps

Drivers approaching Mangere Bridge on the local road network have a choice on whether to access the motorway at Coronation Road or to use one of the local arterials to bypass the motorway and access the motorway at the Mahunga Drive on-ramp. The table below shows the traffic volumes using each ramp before and after the commissioning of the ramp metering system. Ramp metering has contributed to increased use of the Coronation Road on-ramp, instead of drivers continuing to drive through the local neighbourhood and shopping area to reach the Mahunga Drive on-ramp. Approximately 60% of the reduction in volume at the Mahunga Drive on-ramp was from Rimu Road (west) with the remainder from Mahunga Drive (east)

17 Locally Generated Trips

The proportion of local trips versus strategic trips was an important indicator in meeting the secondary objective for the Easy Merge Ramp Signal (ramp metering) trial. This measurement provides an indication of whether strategic trips or locally generated trips have reassigned to the Coronation Road on ramp.

Number plate surveys were conducted on the parallel arterial routes (Rimu Road/Coronation Road on the western side of SH20 and Mahunga Drive on the eastern side) to determine the proportion of traffic on the arterials that continued through to the motorway. Figure 14 shows the proportion of traffic continuing on to the motorway from each route.

The figure shows that there has been significant improvement in encouraging “strategic traffic” to use the Coronation Road on-ramp rather than the Mahunga Drive on-ramp. “Strategic traffic” is defined as traffic that has chosen to use local arterials in preference to the using the motorway. However, on the eastern side, there is still a very high component of “strategic traffic” using the Mahunga Drive on-ramp. This strategic traffic on Mahunga Drive is contributing to the additional delays to locally generated traffic waiting in the queue at the Mahunga Drive off-ramp.

	Morning Peak Period (2hr)			Evening Peak Period (2hr)		
	Sept 2003	After Six Months	Diff	Sept 2003	After Six Months	Diff
Mahunga Drive on-ramp	2,100	1,500	-600	1,750	1,450	-300
Coronation Road on-ramp	800	1,350	+550	950	1,250	+350

Table 2: Changes in traffic volumes at the Mahunga Drive and Coronation Road on-ramps

18 Comparative Travel Time via Coronation Road on-ramp

Recent journey time surveys undertaken indicate that the “strategic” traffic would benefit in terms of travel time if SH20 was accessed from Coronation Road rather than Mahunga Drive.

This is especially the case where motorway conditions force the Easy Merge Ramp Signal to restrict the flow on to the motorway at Mahunga Drive for extended periods of time. Figure 14 shows a comparison of journey times between using Coronation Road and Mahunga Drive.

19 Safety

This site has a bad safety history with approximately 50 congestion related accidents, 10 of these injury accidents, occurred in the weekday peak periods in the four years prior to ramp metering. Of these, 33 were on the motorway and 17 were on the local road network in the vicinity of the Mahunga Drive on-ramp. In the year since ramp metering has been implemented, 13 accidents have been recorded, of which 11 were on the motorway and only 2 were injury accidents.

Since the ramp metering trial has only been implemented for one year and it would be premature to conclude any safety benefits; however, initial monitoring shows no increase in accidents despite increases in throughput. It should be noted that to date, no accidents directly related to the ramp metering operations have been reported.

20 Ramp Signal Compliance

Compliance levels for the ramp meter signal are high. Initially when the trial was implemented some non-compliances were observed, and most likely stemmed from motorists not understanding the system. This was despite the distribution of a flyer explaining the system.

Surveillance using the CCTV camera located nearby shows continuing very high compliance levels now that motorists are aware of the system and how it operates. Cycle times for this site range between 5.5 seconds and 12 seconds.

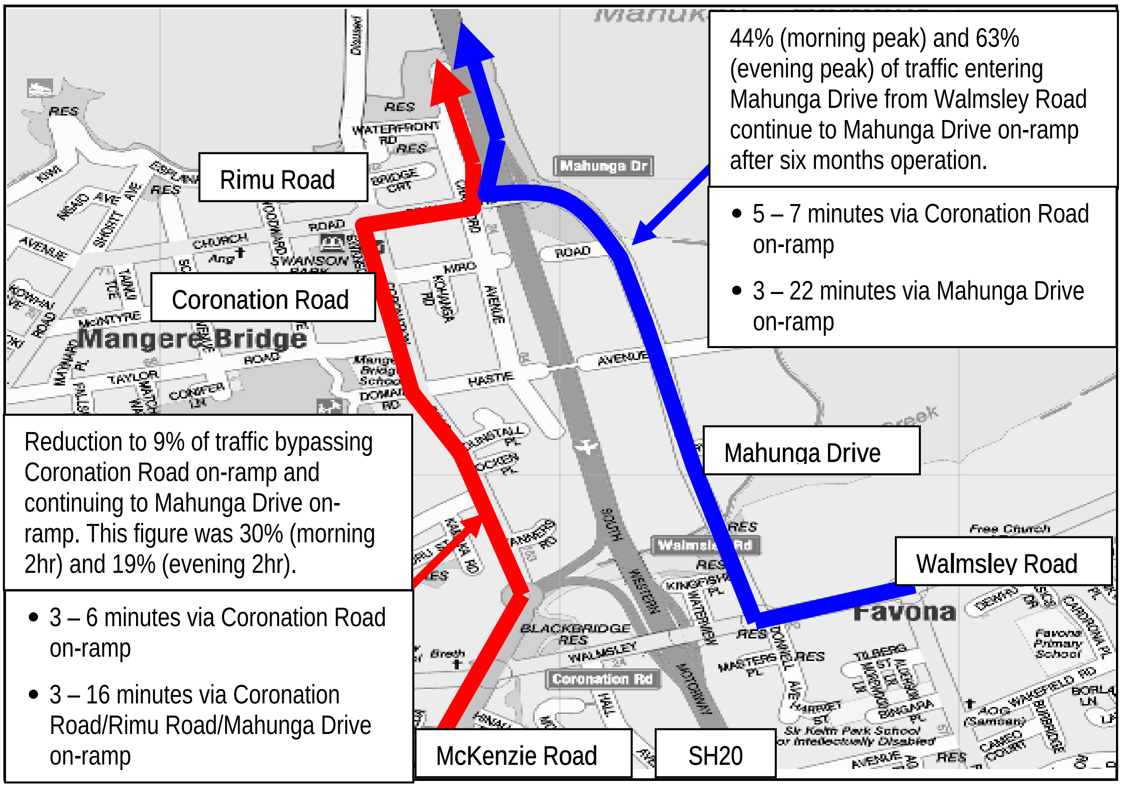

Figure 14: Comparative travel times and strategic traffic levels on local roads

The lower cycle time was the minimum time required for vehicles to stop and then proceed on the next green display. Experience from this trial showed that at shorter cycle times, an increased proportion of individual drivers failed to stop. The upper cycle time was the maximum practical time to encourage vehicle compliance. Many motorists are now rolling up to the signal (rather than reaching the limit line and stopping on red) because they are aware that waiting times at the signal are low (maximum of 10 seconds).

The use of high mounted and low mounted signals has been successful in providing displays visible by both approaching traffic and traffic at the limit lines (warning/stopping function and starting functions respectively). The signals and their location have contributed to the high level of compliance observed.

21 Signage Effectiveness

The signs at Display A (mounted on the signal poles) displaying the words "One Vehicle Per Green Each Lane", in conjunction with the combined green and yellow time of 2 seconds, have proven effective in metering the ramp flow as demonstrated with the high compliance rate discussed above.

The signs at Display B, located on the local roads in advance of the ramp, display the message 'Ramp Signal On' or a blank message when the ramp signal is off. This signage has two functions:

- Indirectly alerting motorists to the potential of queuing on the ramp that is not visible from the right turn lane on Mahunga Drive, and;
- Advising the motorists that the ramp signals are in operation and provide the opportunity for driver to use alternative route.

With Mangere Bridge being the only crossing of Manukau Harbour, the signs need to be located such that motorists have a choice on which ramp to use, rather than choosing whether or not to enter the motorway. In their current location, the signs are unlikely to influence the route choice of motorists, as there is no alternative route once they have reached the on-ramp. This is a site specific issue that may arise during future installations. The location of these signs or supplementary signs where route choice can be affected should be considered carefully as part of future installations.

The message on the sign is effective in advising motorists that the signals are in operation; however the legibility and location of the signs have arisen as issues that should also be addressed for future installations. The sign located on the left hand side of Mahunga Drive for traffic turning right on to the ramp was observed to confuse the occasional motorist, probably not familiar with the system. The yellow LED display was difficult to read from a distance because of the intensity of the flashing yellow signal aspects. This is more evident at night (refer to **Figure** 15). A larger space between the LED sign and the flashing yellow aspects should be considered for future installations.

Figure 15: Advance Warning Sign on Mahunga Drive

The signs at Display C, located near the top of the ramp, include a PW-3 sign and a VMS sign with alternating displays to warn drivers of the ramp signals and the state at which they are in. When the ramp signal is operating (including start-up and shut-down periods) the VMS displays the message “Prepare to Stop”. When the ramp signal is not operating, the VMS displays the message “Ramp Signal Off”. The form and location of these signs have proven to be effective with no occurrences of motorists stopping at the signals when the ramp signal is not in operation and no recorded rear end accidents on the ramp since the commissioning of the ramp metering system.

22 Discussion

Although this ramp metering trial has successfully improved the traffic conditions along SH20, flow breakdown caused by other factors still exist, which influence driver behaviour and route choice in the area. The two specific areas are factors influential to the operation of the isolated ramp meter at Mahunga Drive are the queues from the Neilson Street off-ramp, immediately downstream of the Mahunga Drive on-ramp, and the merge at the SH20/SH20A interchange where four lanes (two lanes on each carriageway) effectively merge into two lanes before the Coronation Road on-ramp.

Figure 16: Photos of the Easy Merge Ramp Signal in operation

At the Neilson Street off-ramp, queues have been observed to extend into the motorway in the morning peak period. Under these conditions, the Easy Merge Ramp Signal may improve this situation slightly by restricting the flow and reducing the number of weaving (merging/lane changing) movements over Mangere Bridge. However, with one lane effectively blocked it is more likely that the reductions in performance would propagate past the Mahunga Drive on-ramp.

Motorists wishing use Mangere Bridge have the choice of accessing SH20 upstream or using parallel local roads (Robertson Road/Mahunga Drive to the east and McKenzie Road/Coronation Road to the west). The traffic conditions through the SH20/SH20A merge influences the choice of whether to use SH20 or continue on the local road network. Once this strategic traffic is beyond the SH20/SH20A merge they have the choice of whether to continue on the local road network to the Mahunga Drive on-ramp, or to use the Coronation Road on-ramp.

Those that continue to use the local road network contribute to the delays imposed on locally generated traffic waiting in the queues at the on-ramp. Journey time surveys indicate the potential for significant time savings via the Coronation Road on-ramp even though the travelled distance is longer. Significant improvements in reducing strategic traffic on the local roads have been achieved on the western side of the motorway. However, the high proportion of strategic traffic on Mahunga Drive indicates that motorists fail to perceive a benefit by using the Coronation Road on-ramp. Effective traveller information where route choice can be influenced could assist in promoting the use of the Coronation Road on-ramp.

Delays at local road interface were an issue. As with the period prior to ramp metering, traffic conditions on the local road network continue to be highly dependent on traffic conditions on the motorway.

In simpler terms, when the motorway operates poorly, the queuing and delay on the local road is significant regardless of the whether the Easy Merge Signal is in operation or not.

Managing the local road queuing has subsequently been addressed in the form of separate storage for queued traffic, a bus priority lane and turning restrictions at the adjacent intersection to prevent bypassing the queue i.e. right turn ban in and out of Crawford Avenue.

23 Conclusion

All of the performance measures for the ramp metering system have been met with encouraging trends with respect to safety. The experience of this trial has led the team to make the following recommendations:

- Ramp metering is an effective tool to improve traffic conditions and safety in the vicinity of motorway on-ramps, a major cause of motorway flow breakdown.
- The adopted signage has been effective in providing positive driver information; however, the location and use of flashing LED’s on Display B needs to be reviewed.
- Other causes of flow breakdown such as off-ramp queue management, forced bottlenecks through lane reductions and the operation of weaving sections, should also be addressed in conjunction with improvements to motorway merge areas, to achieve full benefits.
- The local road interface needs to be well managed.

In conclusion, the Easy Merge Ramp Signal (ramp metering) trial has proven to be successful and has introduced an effective traffic management tool to New Zealand.
A wide application of such a technique is one of the available tools for managing demands along an entire motorway corridor.