Effectiveness of Incident Management on Network Reliability – Stage 2

June 2014

NZ Transport Agency research report LTR-118

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Executive summary

This research, which was conducted from July 2008 to February 2014, investigated how ITS (Intelligent Transport Systems) measures can be used to improve the transport network efficiency during traffic incidents. As congestion on NZ roads increases, the network has less spare capacity that can be used during incidents. It is imperative that such capacity is used optimally.

A previous (Stage 1) report was a scoping study that undertook a literature review and an exploratory investigation of how the effect of ITS measures could be modelled during traffic incidents using a pilot traffic network from Auckland's North Shore.

This Stage 2 report expands on the Stage 1 report by implementing additional ITS treatments and incident scenarios on a larger network. The overall aims of the Stage 2 research project were to:

- Investigate the ability of Intelligent Transport Systems (ITS), such as adaptive signal control (e.g. SCATS®®) and Variable Message Signing (VMS), to detect and respond to traffic incidents.
- Determine the most appropriate traffic management strategies (in terms of overall network reliability) to apply when such incidents are detected.

The research involved undertaking further international literature review followed by the development and testing of an expanded traffic network using micro-simulation (S-Paramics). This network includes a six-lane section (three lanes in each direction) of the Northern Motorway, containing three interchanges, and some adjacent parallel arterial roads. As the traffic signals on those streets are dynamically controlled using SCATS®® (Sydney Coordinated Adaptive Traffic System), it was necessary to interface S-Paramics with SCATS®®, to ensure consistency between the signal timings used during simulation with those that would actually occur.

The expanded study considered:

- assessing the ability of adaptive signal control (e.g. SCATS®®) and variable message signing (VMS), to detect and respond to traffic flow changes resulting from incidents; and
- determining the most appropriate traffic management strategies (in terms of overall network performance) to apply when incidents are detected.

The expanded model network included a greater number of paths to which traffic can divert to avoid congestion caused by an incident. In addition, data relating to changes in traffic flows and network performance caused by an actual incident were collected. This was used to assess changes in network flows and diversion rates when VMS displays were implemented. The resulting analysis found diversion rates of at least 30% to upstream off-ramps when appropriate messages were communicated via VMS.

Two hypothetical incident scenarios were considered:

- a blockage on the motorway; and
- a kerb-lane closure on an arterial road adjacent to the motorway.

The first scenario was studied, both with and without physical mitigation (i.e. implementing VMS and allowing motorway traffic to use the hard-shoulder), while the second scenario was studied, both with and without revising the SCATS®® signal plan to alleviate the effects.

In all cases, five model simulations were run (with different random seeds) to assess the level of variability of the network performance. It should be noted that the trip matrix was 'fixed' (i.e. it was assumed that the duration and impact of the incidents would not result in changes in trip generation, trip distribution or mode choice).

The simulation runs enabled various measures of network performance to be used for assessing the effectiveness of incident mitigations, including:

- average travel time, distance and speed;
- variability in travel time, distance and speed;
- the time taken for the above measures to return to their ‘no incident’ values (i.e. the network recovery time).

The amount of detouring can be estimated from the increase in average travel distance resulting from an incident. It is also possible to assess the relative magnitudes of the impacts on travel time, etc. on the performance of the motorway and the performance of the arterial roads.

For the motorway blockage scenario, the mitigation was estimated to produce a 25% increase in average speed across the entire network and a 9% increase in the average trip distance, giving a 20% reduction in the trip times. The reduction in the standard deviation of trip times was much larger, being about 80%. These effects were ‘network averages’, and an investigation of some selected diversion routes revealed that the estimated effect of the mitigation on speeds on those routes was much less, varying from about 2% to 7%.

For the arterial road lane closure, the mitigation was estimated to produce quite small improvements in average travel times (between 1% and 2%), although again the standard deviation reduced quite notably by ~45%. An investigation of some selected diversion routes revealed that the estimated effect of the mitigation on speeds on those routes varied considerably, from a 3% decrease in speed for one route to a 14% increase in speed for another route. That is, a targeted SCATS®® plan to optimise certain diversion routes may adversely affect the speeds on other routes.

The research has highlighted the complexities involved in identifying effective treatments for mitigating the effects of incidents. While specific case studies may produce solutions that are effective in particular situations, they might not be nearly as effective in other situations. For a large complex network, it may be necessary to have a large number of incident management plans, to cover the range of incident scenarios that might occur. The report concludes with a discussion of the key tasks involved in developing a ‘template’ for a consistent process for identifying the most significant risks to a network, comparing the treatment options, and developing suitable contingency management plans.

Abstract

This research investigated how ITS (Intelligent Transport Systems) measures), such as adaptive signal control (e.g. SCATS®®) and Variable Message Signing (VMS), can be used to improve the transport network efficiency during traffic incidents. Following a literature review, a motorway and arterial road traffic network was modelled to determine the most appropriate traffic management strategies (in terms of overall network reliability) to apply when such incidents are detected.

For a motorway blockage scenario, the chosen mitigation (implementing VMS and allowing use of the motorway hard-shoulder) was estimated to produce a 20% reduction in average trip times, although on some selected diversion routes the estimated effect was less than 7%. The reduction in the standard deviation of trip times was much larger (~80%). For an arterial road lane closure, the chosen mitigation (revising the SCATS®® management plan) was estimated to produce quite small improvements in average travel times (<2%). The estimated effect on various diversion routes varied considerably up and down.

For a large complex network, it may be necessary to have a large number of incident management plans, to cover the range of incident scenarios that might occur. A ‘template’ process is proposed for identifying the most significant risks to a network, comparing the treatment options, and developing suitable contingency management plans.

1 Introduction

This report summarises Stage 2 of a NZ Transport Agency research project (LTR 0118). The Stage 1 report (LTR 0084) was a scoping study that investigated how ITS (Intelligent Transport Systems) measures can be used to improve the transport network efficiency during traffic incidents.

As congestion on NZ roads increases, the network has less spare capacity that can be used during incidents. It is imperative that such capacity is used optimally. This Stage 2 report expands on the Stage 1 report by implementing additional ITS treatments and incident scenarios on a larger network.

1.1 Stage 1 Report Summary

The Stage 1 research (Koorey *et al* 2008) was undertaken in New Zealand during 2006-2007. This research included:

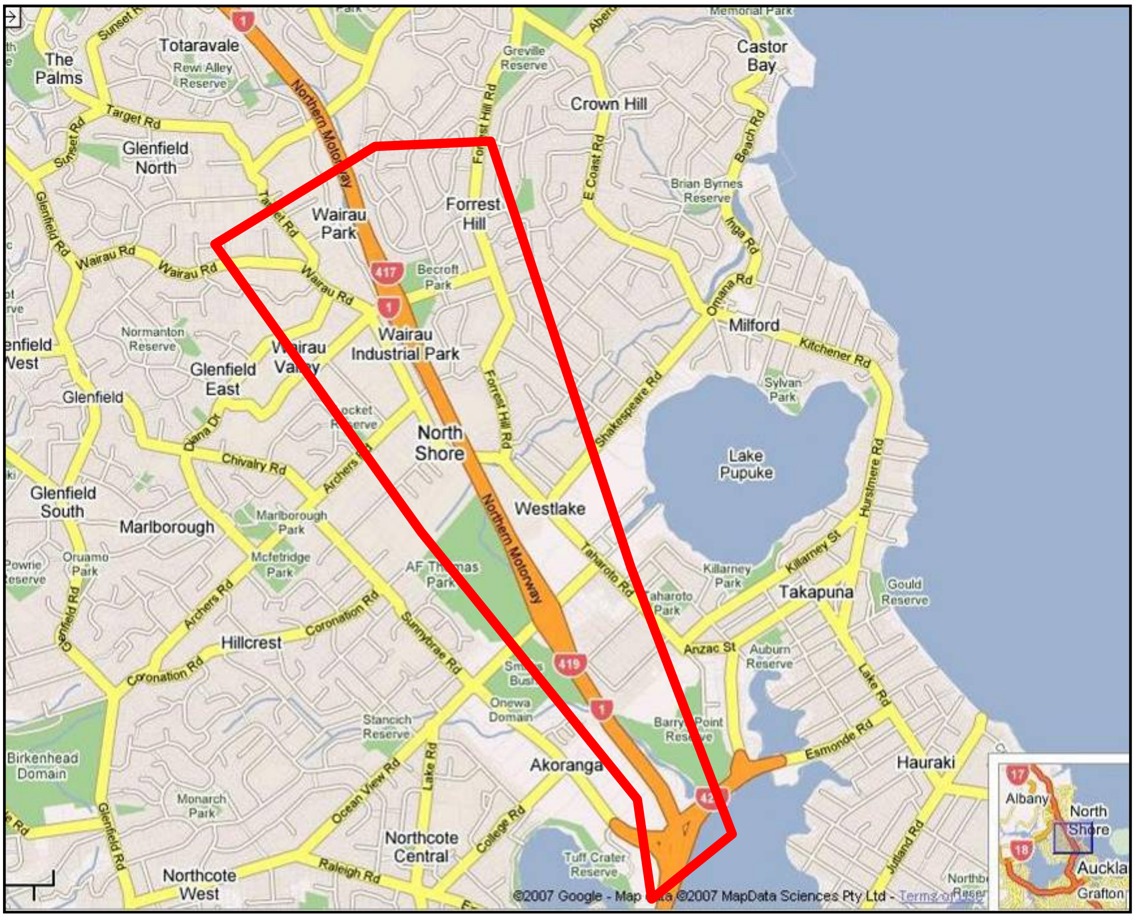
- A literature review of techniques and software/systems currently used in NZ and elsewhere in the world to manage traffic congestion and respond to incidents.
- An exploratory study modelling incident detection and response in a NZ urban network (Auckland North Shore) using micro-simulation (S-Paramics).

The literature review revealed that although considerable research has been undertaken in the areas of incident detection and incident management, ITS methods such as adaptive signal control (e.g. SCATS®®), and network reliability measures, little work has been done to bring all three research areas together.

The exploratory model network used was the “Wairau Road” network on Auckland’s North Shore. This was an existing model calibrated to 2006 PM peak period conditions. This model uses SCATS® control for the signalised intersections through S-Paramics interfacing with SCATS® via FUSE software. The area covered by this model is shown in Figure 1 and Figure 2; it includes a length of the Northern Motorway (SH1) with three interchanges and some adjacent parallel arterial routes. The relatively small area covered by this model offered limited route choice on the arterial network.

Only one incident scenario was modelled. The incident modelled was on the northern motorway (SH1) between Tristram and Northcote interchanges, from 3:15pm-4:30pm (before evening peak). It included closure of the northbound kerb lane from 3:30pm to 4:00pm and the additional closure of the centre lane from 3:30pm to 3:45pm.

Figure 1: Wairau Road Model Study Area



Only two ITS treatment were tested against these scenarios:

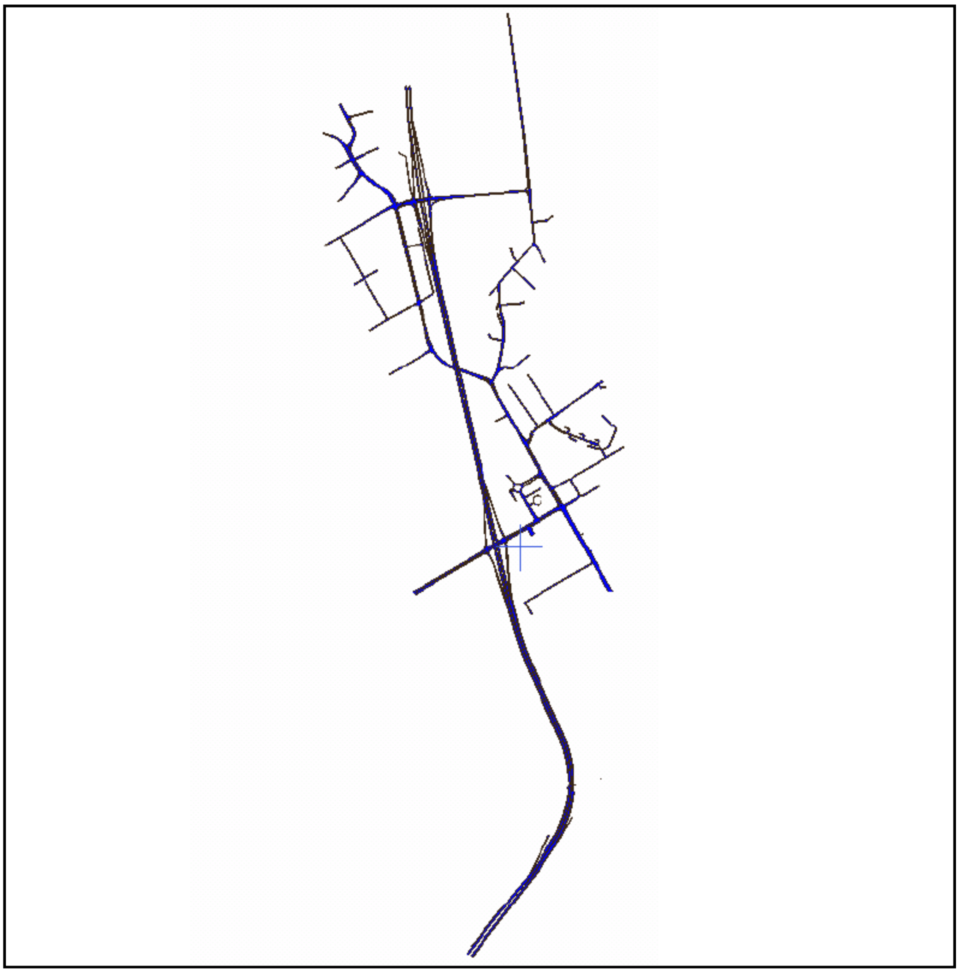
- Existing SCATS® configuration provided in the base condition
- A "good" SCATS® configuration optimised for re-routing from the Motorway

The exploratory microsimulation modelling study found that:

- SCATS® can be modified by an operator in anticipation of additional demand due to diversions resulting from an incident to reduce the delay to the diverted traffic
- SCATS® can be modified by an operator at the time of the incident in anticipation of the change in demand from an incident
- Although SCATS® will respond to the change in demand caused by traffic diversions due to incidents, an immediate and targeted intervention will produce better results
- The benefits of incident management interventions such as SCATS® adjustment may be limited to particular journey paths. Microsimulation modelling can help to identify on which routes efforts should be concentrated.

Both the literature review and the preliminary modelling highlighted the need for more work to be undertaken in this area in New Zealand.

Figure 2: Wairau Road Modelled Paramics Network



1.2 Research Objectives

The overall aim of the Stage 2 research project is to:

- Investigate the ability of Intelligent Transport Systems (ITS), such as adaptive signal control (e.g. SCATS®) and Variable Message Signing (VMS), to detect and respond to traffic incidents.
- Determine the most appropriate traffic management strategies (in terms of overall network reliability) to apply when such incidents are detected.

In Stage 1 of the current research, a literature review was completed, a preliminary network model identified and obtained, and incident scenarios and treatments tested using the model. Stage 2 of the project builds on the previous research by expanding the modelling in terms of area modelled, incident scenarios tested and treatment options, as well as incorporating a field data collection component to more accurately calibrate the models used and investigating how motorists respond during incidents.

1.3 Research Tasks

A number of tasks were identified for this project

- Additional literature review, to assist with techniques and software/systems to be tested and to update ITS developments since the Stage 1 report.
- Field data collection to confirm the accuracy of the simulation model findings under incident conditions.
- Basic network modelling to create a network for more detailed assessment of incident scenarios and treatments.
- Further network modelling of alternative scenarios and treatments.
- Development of a template for using traffic modelling to assess incident management strategies.

The incident modelling required assessment of a number of

- Incident Scenarios
- Treatments to manage the Incident
- Performance Measures

The following sections describe the findings. Note that, due to significant difficulties with some of the modelling tasks (e.g. calibration), not all of the desired scenarios and treatments were able to be tested.

2 Literature Review

An international literature review was undertaken during the Stage 1 report (Koorey *et al* 2008) and the reader is referred to there for more detail. The Stage 1 literature review revealed that, although considerable research has been undertaken in the areas of incident detection and incident management, ITS methods such as adaptive signal control (e.g. SCATS®), and network reliability measures, little work has been done to bring all three research areas together.

A further literature review was undertaken as part of the Stage 2 research to determine any developments in these areas since the conclusion of the Stage 1 research. This section identifies additional relevant literature that was identified.

Much technological advancement has occurred recently, including a dramatic increase in the prevalence of motorists with smart phones with internet access, GPS, Bluetooth, etc. Smart phones can be used to intelligently disseminate information, and real-time information can easily be delivered when relevant to the motorist. A significant concern still remains however as to the effect of such communications on driver distraction and road safety (Vellequette 2012, Rowden & Watson 2013). Smart phones can also be used to easily gather real-time information from motorists at low cost (Herrera *et al* 2009, Shalaby *et al* 2009).

2.1 Incident management

Historically, long-term estimation of the impacts of incidents that occur along a corridor have been based on either or both of two approaches:

(1) ***modelling*** approaches, which take generalised inputs of incident characteristics, traffic volumes, and roadway geometries to simulate the delay caused by incidents; and

(2) ***measurement*** approaches, which develop correlations between historical delay and incident data.

Hadi *et al* (2013a) for example, uses macroscopic and microscopic simulation modelling (FREEVAL and CORSIM respectively) to estimate incident delays of previous observed incidents. Meanwhile, Barkley et al (2013) uses a measurement approach to develop a linear regression model of delay, capacity reductions and clearance times, based on historical incident data from highways in California's Bay Area.

Selecting the correct operational strategy to implement during an incident is important. Traffic models can also be used to test different operational plans for different incident conditions to determine the most appropriate operational plan including detour routes and optimal traffic signal operation. Recent studies have tried to use "real-time" traffic models of incidents as they occur to determine the best course of action. This follows on from the real-time modelling investigations on the Birmingham motorway network reported previously (Koorey *et al* 2008).

Garcia & Perarnau (2009) noted that AIMSUN microsimulation software has developed a tool called "AIMSUN Online" that allows users to model traffic incidents in real time. An advantage cited of using AIMSUN is that it can run relatively large models very quickly. It uses "demand profiles" to match the existing traffic conditions to a historic demand matrix. Once the correct base matrix has been determined, incidents are modelled and various scenarios can quickly be tested to determine the appropriate solution. This procedure has been used in Singapore, Madrid and Milan.

Hadi *et al* (2011) undertook research into using CORSIM to evaluate incident scenarios and to calibrate and compare incident and non-incident scenarios. CORSIM is a US-developed microscopic traffic simulation software package for signalised networks, highways, and freeway systems. As part of Florida DOT's "SunGuide" project (FDOT 2012), a state-wide programme to manage and maintain the Intelligent Transportation Systems in the region, CORSIM is used to evaluate ITS measures. Florida and other US eastern coastal states have also been investigating the use of cell phone vehicle probe data for monitoring along the I-95 freeway corridor.

In summary, while micro-simulation can be a valuable tool for evaluating and optimising incident scenarios, this can be difficult to analyse in real time due to the time it takes to run the simulations. Early detection and clearing of incidents is important. Automated incident detection is generally still not good enough, but data collection is improving through technological advancements, such as smart phones, Bluetooth, etc. The studies also concluded that looking at overall performance measures of the network was not necessarily the best measure to use in an incident condition (as there can be a large number of network users relatively unaffected), but rather the performance on the detour routes.

2.2 Adaptive signal control

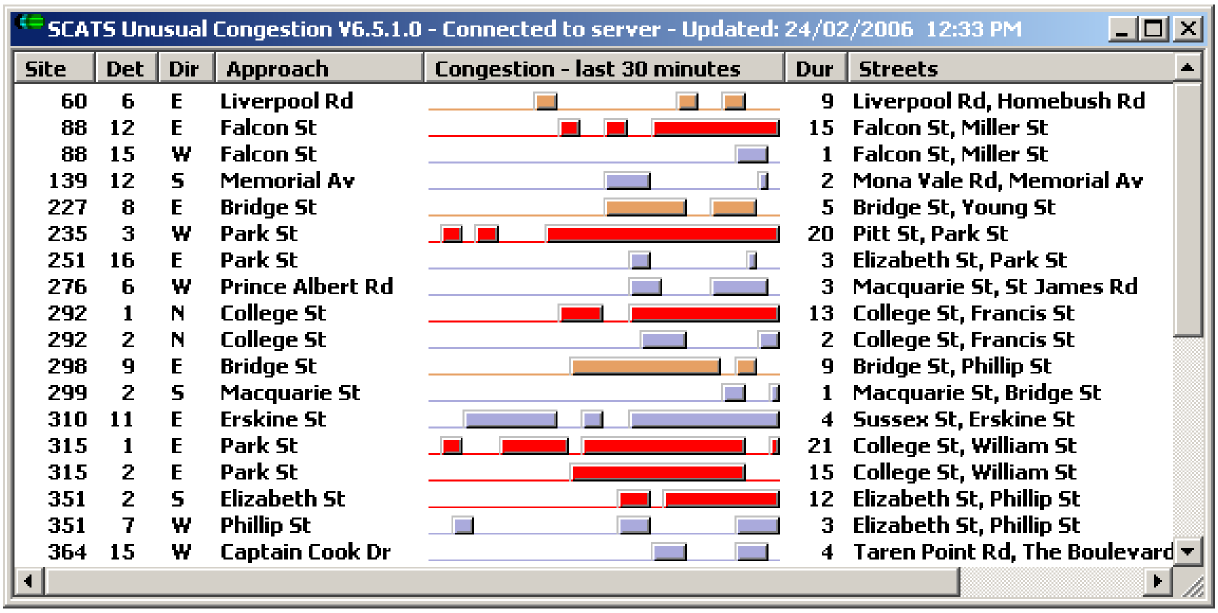
Studies continue to show the benefit of adaptive (or at least responsive) traffic signal control such as SCATS®. Luk *et al* (2012) examined the possibility of using upstream and downstream vehicle detectors as part of adaptive signal control systems like SCATS® in congested networks. This report concluded that upstream detectors can be used to detect when a change in demand and when spillback starts to occur, and recommends using a "gating" technique to restrict traffic from entering an already congested network. Ramp signalling is an example of such a gating technique.

The following sections describe tools and techniques in SCATS® that could be used together to detect unusual congestion and then, when confirmed, provide priority along a chosen complete diversion route.

2.2.1 Unusual Congestion Monitor

The unusual congestion monitor tool in SCATS® (RTA 2006) can be configured to detect when flow over detectors is not what is expected. SCATS® considers a lane to be unusually congested if the DS is high and the flow over the detector is a lot lower than would be expected. SCATS® does not detect queues as the detectors are at the stop line. Instead, this unusual congestion is due to downstream queues blocking back. SCATS® monitors how many minutes a lane is unusually congested. Thresholds for the duration of unusual congestion are set in the unusual congestion monitor and if those thresholds are met, the intersection affected will appear in the unusual congestion monitor (see Figure 3). The different shading in Figure 3 is a measure of how long the usual congestion has occurred. The unusual congestion monitor can therefore be used to detect the congestion resulting from an incident, after which a suitable treatment can be applied.

Figure 3: SCATS® Unusual Congestion Monitor (RTA 2006)



SCATS Unusual Congestion V6.5.1.0 - Connected to server - Updated: 24/02/2006 12:33 PM

Site	Det	Dir	Approach	Congestion - last 30 minutes	Dur	Streets
60	6	E	Liverpool Rd		9	Liverpool Rd, Homebush Rd
88	12	E	Falcon St		15	Falcon St, Miller St
88	15	W	Falcon St		1	Falcon St, Miller St
139	12	S	Memorial Av		2	Mona Vale Rd, Memorial Av
227	8	E	Bridge St		5	Bridge St, Young St
235	3	W	Park St		20	Pitt St, Park St
251	16	E	Park St		3	Elizabeth St, Park St
276	6	W	Prince Albert Rd		3	Macquarie St, St James Rd
292	1	N	College St		13	College St, Francis St
292	2	N	College St		2	College St, Francis St
298	9	E	Bridge St		9	Bridge St, Phillip St
299	2	S	Macquarie St		1	Macquarie St, Bridge St
310	11	E	Erskine St		4	Sussex St, Erskine St
315	1	E	Park St		21	College St, William St
315	2	E	Park St		15	College St, William St
351	2	S	Elizabeth St		12	Elizabeth St, Phillip St
351	7	W	Phillip St		3	Elizabeth St, Phillip St
364	15	W	Captain Cook Dr		4	Taren Point Rd, The Boulevard

2.2.2 Variation Routines

SCATS® has many in-built variation routines that can be used to modify the signal operation at an intersection if certain conditions are met. The following variation routines are based on the same calculations used to detect unusual congestion:

- Test detectors for congestion
- Test strategic approach (group of detectors in specified phase) for congestion

An intersection can be configured to do the above tests and if congestion is detected, then the signal operation can be modified to accommodate the congestion. For example, another variation routine could be used to bring in a particular split plan, cycle plan or link plan.

Luk & Green (2010) undertook a case study in Melbourne using the Variation Routine 83 (VR83) function in SCATS® to determine whether VR83 can balance traffic flow or density at the intersection, route or network level. The VR83 function in SCATS® uses two conditions to determine when to cap the degree of saturation (DS) in SCATS®. DS (a measure of traffic flow density measured at the stopline, representing the level of congestion) is a key parameter in allocating green time to a movement – the higher the value of DS, the more green time will be allocated to that movement. VR83 also looks at the ratio of the maximum possible throughput volume divided by the observed throughput volume. The VR83 function allows SCATS® to redistribute green time when it cannot be efficiently utilised by a movement due to downstream congestion blocking progression of that movement.

2.2.3 Action Lists

Action lists (sometimes referred to as "action plans") are another feature of SCATS® that can be used to make specific changes to an intersection operation. For example, changes can be made to the cycle time, split plan or intersections can be linked. Action lists can be implemented by time of day through the SCATS® Scheduler, or can be called through variation routines.

A series of actions could be created to provide priority for a diversion route. These actions could be implemented manually when an incident is detected, or could be set to come in through a variation routine that is used to detect unusual congestion. Action lists can be written in advance for various incident scenarios, which make them easily implemented.

2.3 Traffic Modelling

As well as using traffic models for determining real-time incident plans, traffic models continue to be used to evaluate "what-if" incident scenarios.

Kamga *et al* (2011) looked at how network performance is affected during an incident, by simulating incidents in a dynamic traffic assignment model. A case study was performed on part of the greater Chicago network, allowing for alternative routes for origin-destination (OD) pairs. A base case scenario was generated to depict operational characteristics of the network under normal traffic flow conditions. Then, an incident was emulated and two sub-cases were modelled:

- An incident scenario where all drivers were assumed to have ***no information*** on the incident. Where possible, all drivers are assumed to follow their current (or ''no incident'') paths as determined by the base case.
- An incident scenario where all drivers are assumed to have ***perfect information*** of the incident conditions. The model estimated the new dynamic user equilibrium and reassigned traffic across the network.

Berdica *et al.* (2003) also proposed such an approach, to get upper and lower bound estimates of the impact of disruption. In practice, a real-world scenario may be somewhere between these two extremes, depending on the level of traveller information available to motorists.

The results from Kamga *et al* (2011) confirmed that an effective traveller information system has the potential to ease the impacts of incident conditions network wide. However the results also suggested that incidents have a different impact on different OD pairs. The use of traveller information to help reassign traffic may detriment some OD pairs while benefiting other OD pairs.

Kim et al (2013) used a scenario-based process to model the likelihood of incidents given different background conditions, such as weather. From this, various reliability performance measures could be determined and compared. The authors identified two main approaches to modelling travel time reliability due to incidents:

(1) A "Monte Carlo" approach, where ***all possible scenarios*** that could occur during the given temporal and spatial boundaries are generated to introduce realistic variations in the resulting travel time distribution. Because each scenario generated is equally likely, a simple aggregate of travel time distributions from a large number of simulation runs will obtain the most likely (probable) outcome of a set of reliability performance indicators for the given time and space domains.

(2) A "mix and match" approach, where ***specific scenarios of interest*** are manually selected by choosing various combinations of scenario components. By assigning the probability that each particular scenario will occur (e.g. an accident will happen but not during heavy rain), a probability-weighted average of travel time distributions under all the modelled scenarios can be used as the expected travel time distribution to approximate the overall reliability measures.

The choice of one method over the other probably comes down to the availability or otherwise of good data about the relative distributions of key modelling inputs such as traffic flows and weather conditions. The first approach is also computationally more demanding.

2.4 Diversion Rates

Many incidents typically result in a drop in capacity along the affected road; the ability to divert existing and future traffic to alternate routes therefore becomes quite critical to the timely recovery of the affected road and the optimal travel time for all travellers. Information systems such as Variable-Message Signs (VMS) and traffic website announcements are often used to encourage traffic to avoid the affected area.

However it is typically difficult to determine the likely take-up of alternate routes, thus making it difficult to model these effects using a traffic model. Whilst some road users may follow the detour guidance provided, others may ignore it due to either:

(a) a lack of familiarity with the alternate route(s),
(b) a scepticism about the actual severity of the incident and its effects, or
(c) a belief that sufficient numbers of other travellers will divert, thus making travel times on the affected road tolerable.

Other factors are also likely to influence the diversion take-up rate, including the severity and likely duration of the blockage, the nature of the message disseminated, and the importance of getting to the trip destination on time.

A simple measure of the "diversion rate", as defined by Foo *et al* (2008), is to compare the off-ramp flows prior to the incident with the flows on the main highway ("main-line"). Thus, the diversion rate *DR* can be determined:

$$DR(\%) = \frac{RF_t}{MF_t + RF_t} \times 100$$

where RF_t represents the ramp flow at time *t* and MF_t is the mainstream flow at time *t*.

If flow data is available continuously (e.g. in-ground loops), then *DR* can be monitored over time using regular time intervals of data. Other researchers have looked to use data from drivers' Bluetooth devices as a means of sampling diverted trips (Effinger *et al* 2013). Note that, even without an incident, it is likely that this measure will not be zero, due to normal off-ramp behaviour. Thus the "incident DR" must be determined by comparison with the average "normal DR" during non-incident times.

Methods to determine diversion rates for various incident scenarios fall into two main categories:

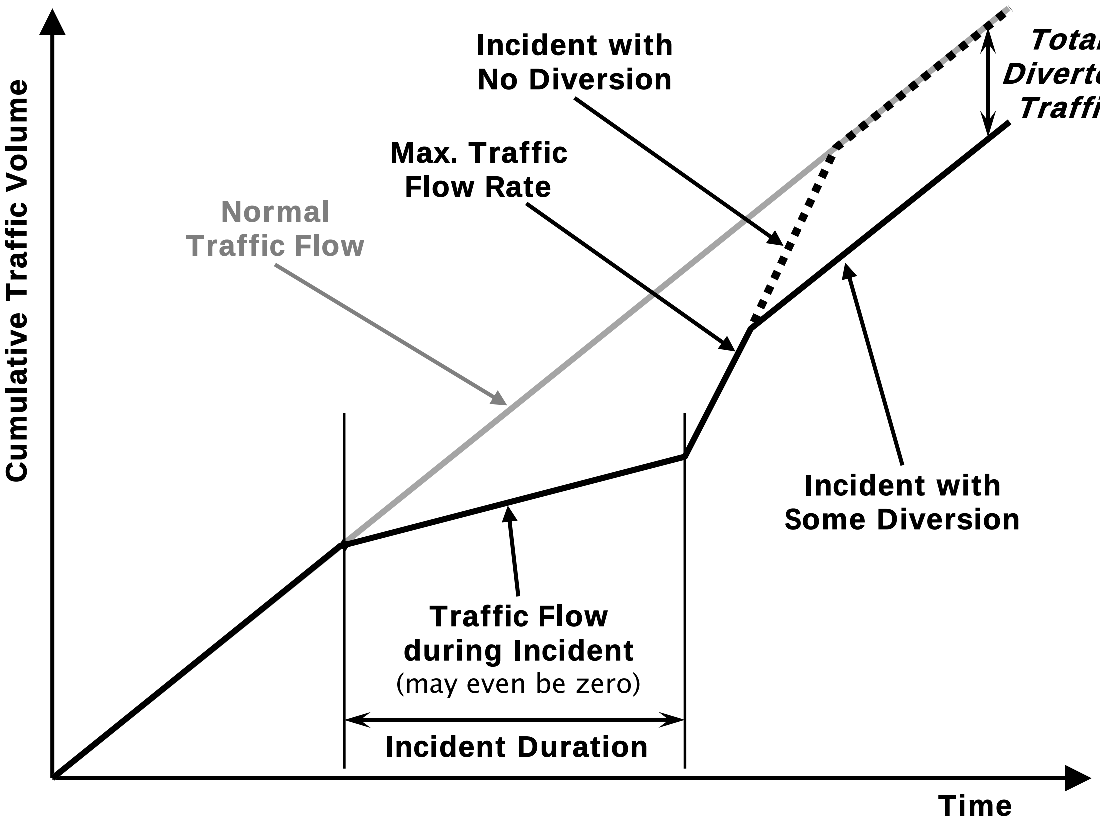
(1) "Stated preference" methods, where ***potential*** users of the roadway indicate their likelihood to use a diversion route in a given hypothetical scenario. This could be via a qualitative survey or via driver simulation tests.

(2) "Revealed preference" methods, where the behaviour of ***actual*** users of the roadway is monitored during incidents (or reported later via survey) to determine the take-up of diversion routes (e.g. monitoring off-ramp counts). From this historical data, it is inferred that future incidents will evoke similar responses.

Hadi *et al* (2013b) developed a method to estimate overall traffic diversions using just main-line detector data without the need for off-ramp detectors. This was based on observing the cumulative traffic volumes along the route during and after an incident and comparing these with the typical (non-incident) flow; any difference would reflect a level of diverted traffic. Figure 4 illustrates graphically how an incident with some diversion would result in a lower cumulative traffic volume over the same time period, compared to an incident without any diversion.

The validity of the developed methodology was verified by comparing the estimated values with real-world data. Case studies of the developed method found that the average diversion rate was about 10%-35% for 3-lane and 4-lane freeways depending on the number of lanes blocked. A linear relationship between the average diversion rate and the “lane blockage ratio” (proportion of lanes closed) was also developed, indicating that there is a general trend of increase in diversion with the increase in the lane blockage ratio.

Figure 4: Estimated Diversion Rate (adapted from Hadi et al 2013b)



Yin et al (2012) also found a relationship between the magnitude of the traffic flow disruption and the rate of diversion, through an empirical study examining loop detector data and incident records on Interstate I-66 in northern Virginia. Increased incident duration and reduced speeds on site also increased the likelihood of traffic diverting. Interestingly, commuters seem to exhibit more inertia; periods of time with greater levels of non-work traffic (e.g. off-peak, weekend) had a higher level of diversion as well.

Variable Message Signs (VMSs) can potentially influence diversion rates, by warning motorists when approaching incident sites and possibly suggesting alternative routes. It has been difficult to determine general rules about the effectiveness of VMS messages however, mainly because each situation has different dynamics surrounding the options available to travellers. For example, Chatterjee & McDonald (2004) reviewed VMS trials in nine European cities and found that, while typically 40-90% noticed VMS messages about congestion and incidents (and comprehension of the messages was generally over 90%), only 3-31% actually diverted from their original route, with an average rate of 11%. Meanwhile, Foo *et al* (2008), in comparing the effect of VMS signs on transfers between local and express lanes on a freeway near Toronto, Canada, found that the long-term change in *DR* following a new sign message was only 1-2%, although there was often a more significant change in the initial 10 minutes or so.

3 Network Modelling

The following sections outline the modelling work undertaken for this research. Considerable difficulty was encountered in modelling the required incidents, reflecting the complexity of this task.

3.1 Objectives Identified from the Previous Study

Based on the considerations from the Stage 1 study (Koorey *et al* 2008), the proposed research involved a number of key factors to be tested:

a. **Incident Scenarios** to be replicated: Combinations of different types of incidents were considered such as:

- Planned (e.g. event) or unplanned incidents
- Incidents on the motorway vs those on the surrounding arterial network
- Varied capacity reduction from speed reduction to single lane blockage to total road closure
- A range of response times by authorities in resolving the incident

b. **Management Treatments** to be tested: The work to date identified various treatments that could be evaluated:

- Letting the existing SCATS® setup automatically adjust to the new situation by itself (either in an optimised or sub-optimal SCATS® configuration)
- Changing SCATS® signal timing plans so that alternative detour routes are given greater priority
- Providing driver information (e.g. through dynamic VMS signage or in-car navigation), advising motorists of the incident and suggested detours
- Limiting additional vehicles into the incident-affected section, e.g. via ramp metering or reduced signal phases
- Temporarily reallocating roadway space, e.g. allowing shoulder or bus-lane use by general traffic, or reassigning variable traffic lanes

c. **Performance Measures** to be evaluated: From the simulation runs, various measures can be defined and collected to evaluate the effectiveness of treatments:

- Overall total network travel times
- Variability in vehicle travel times *(NB: in a stochastic model like Paramics, this is also related to the model inputs and the model stability)*
- Amount of detouring undertaken by motorists
- Time to “recover” to normal travel times following an incident
- Relative performance of motorway network vs arterial network

Particular questions to be assessed were:

- How well do existing traffic signal control systems (e.g. SCATS®) identify and handle significant incidents, in terms of network reliability?

- How do specific incident management plans compare with default schemes, when handling significant incidents?
- What is the impact of different response times to the overall performance and recovery of the network during and after an incident?
- How can incident management plans be automatically invoked when significant incidents occur?
- How do motorists perform when faced with congestion related to an incident, particularly when provided with information about the situation and alternatives?

Because of difficulties with the modelling, some planned investigations from the original proposal were not completed and thus lend themselves to further investigations later.

As in the previous research, S-Paramics (developed by SIAS) and SCATS® software (RTA), linked by the FUSE package (Aurecon), was used to model the road network, control traffic signals, and respond to simulated incidents. This software allows the user to simulate various real-world scenarios where drivers respond to incidents by changing routes, and traffic signals are adjusted to better manage the changed traffic flows. Key information such as overall travel times can then be extracted for analysis.

3.2 Incident Data Collection

Incident data was collected for actual incidents that occurred on Auckland's motorway network. The following data was received from the Joint Transport Operations Centre (JTOC) and the Auckland Motorway Alliance (AMA):

- Incident Reports: Including detail of incident and traffic management put in place. Time of incident, response and when the incident was cleared.
- Motorway Vehicle Count Data: Main-line vehicle volumes on the State Highway Network. Some detector data for earlier incidents was not available due to construction work on the Northern Busway.
- SCATS® vehicle counts: Vehicle counts for each lane at the stopline of signalised intersections.
- SCATS® signal timings: Cycle time and phase split times.

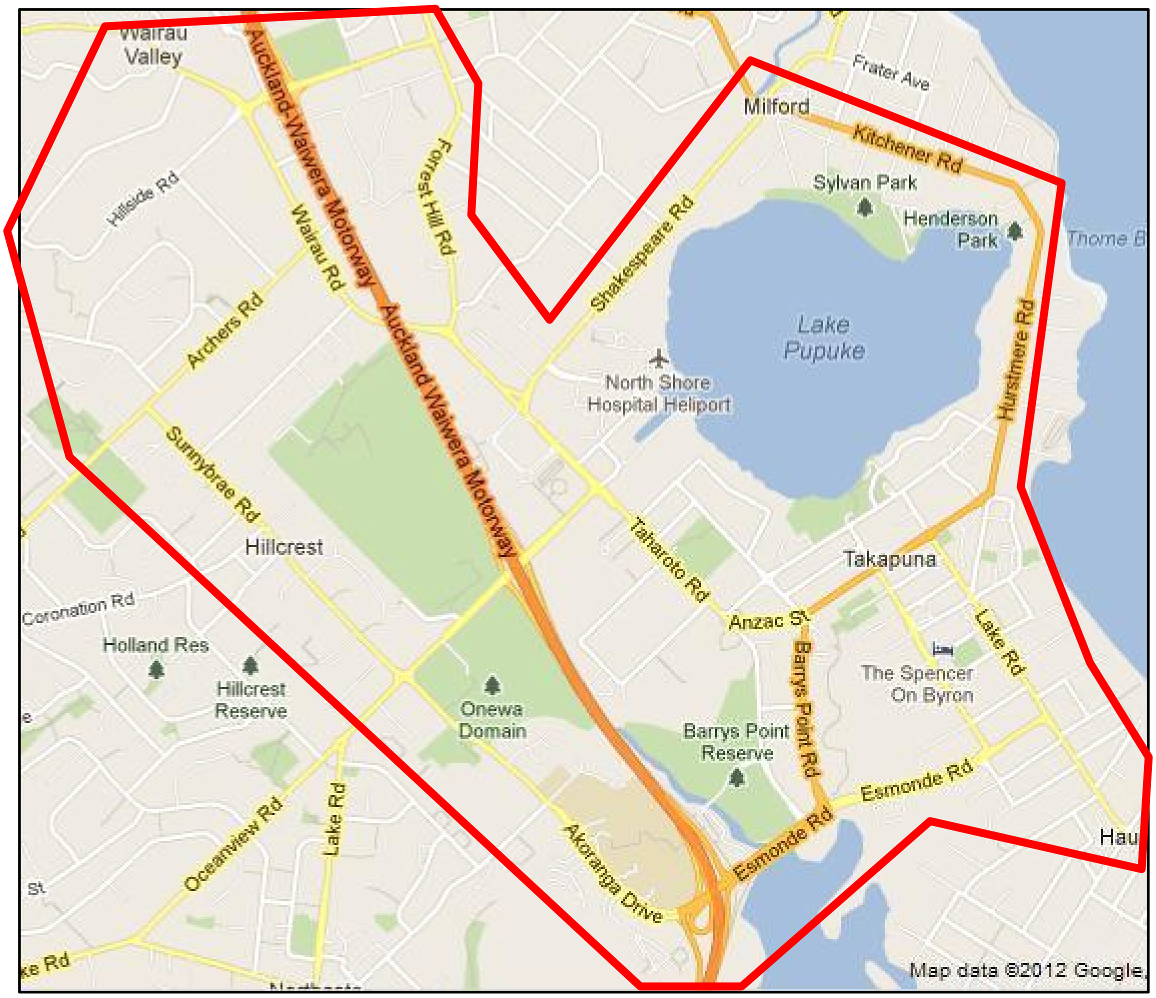
From this data, potentially suitable incidents for replicating in the model could be identified. Section 3.4.1 details an actual incident for which traffic data was able to be collected.

3.3 Expanded Model Network

An expanded model was created by combining the "Wairau Road model" used in Stage 1 with the "Takapuna model", which was also created for the (former) North Shore City Council to help assess another development project. This expanded model (see Figure 5 and Figure 6) offered more route choice for motorists to divert to during incident conditions. Again, the model covers the PM peak and peak-shoulder period only.

This combined model is very complex. There were many calibration issues and, as a result, the combined base model does not meet NZ economic evaluation calibration criteria (NZTA 2010). Many restrictions were made to ensure vehicles route choice was appropriate. Running time (through FUSE) became greater than real time due to the size and complexity of the model. See the calibration report in Appendix A and further discussion in Section 3.4.3.

Figure 5: Expanded North Shore Model Study Area



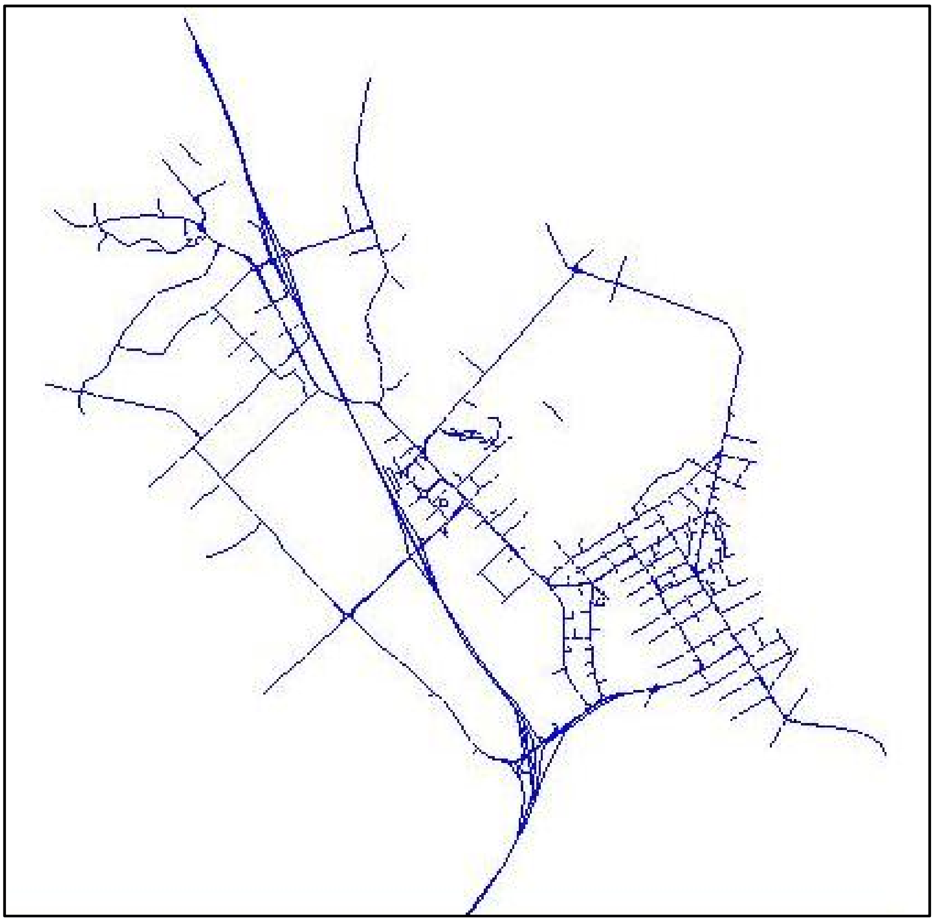
For any further research of this nature, it may be simpler in the future to test out some theoretical scenarios using a hypothetical model network created specifically for that purpose. Given the limitations in being able to calibrate a "real world" model for incident conditions, such a hypothetical model is likely to be just as useful in assessing the performance of different incident scenarios and treatments.

3.4 Incident Scenarios

From the data collected for incidents on the Auckland Motorway network, one suitable incident was identified that occurred in the area and time period modelled - Section 3.4.1 describes it in more detail.

Two other hypothetical incident conditions were modelled on both the motorway network and the surrounding arterial road network. Details of these incidents are described in Section 3.4.2.

Figure 6: Expanded North Shore Modelled Paramics Network



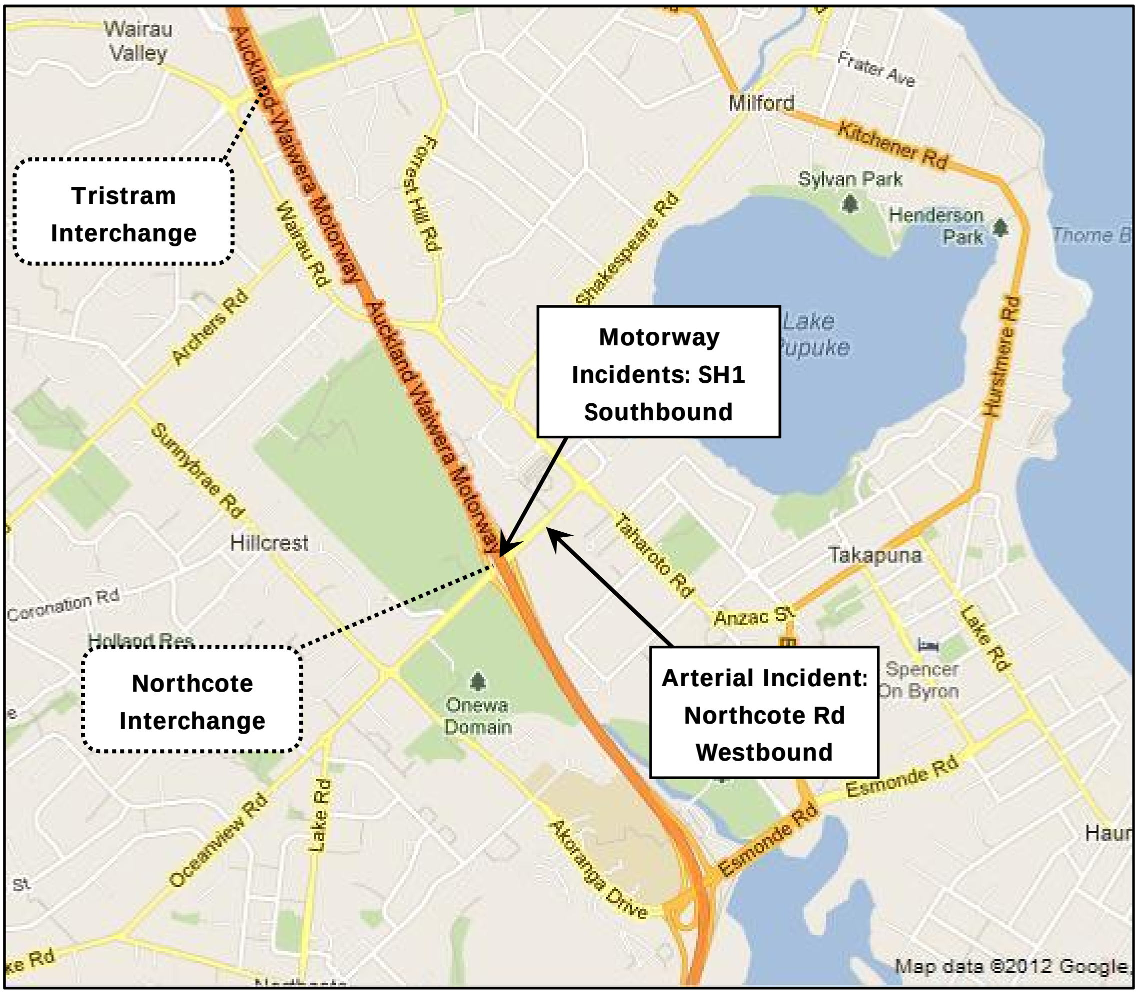
3.4.1 Known Incident

This incident occurred on SH1 Southbound between the Northcote off- and on-ramps and involved a full motorway closure for that direction. Some key attributes of this incident:

- The incident occurred sometime before 17:45, which coincided with PM-peak traffic, but was in the off-peak direction.
- There was a full southbound motorway closure from 17:50-19:33
- Vehicles were diverted off at the Northcote off-ramp and then were allowed to proceed directly through to get back on the motorway via the Northcote on-ramp.
- VMS also directed traffic to exit at the Tristram exit immediately preceding the Northcote interchange.
- The signal plan was locked (i.e. not allowed to adaptively change) at the Northcote interchange signalised intersection from 18:00-19:15
- Queued traffic had cleared by 19:33

The location of this incident is shown on Figure 7.

Figure 7: Locations of Incidents Modelled



3.4.2 Hypothetical Incidents

Two hypothetical incident conditions were modelled to evaluate different ITS treatments for incident management:

- An incident on the motorway network
- An incident on the surrounding arterial network

Proposed “treatments” for these incidents are discussed in Section **Error! Reference source not found.**.

3.4.2.1 Motorway Incident

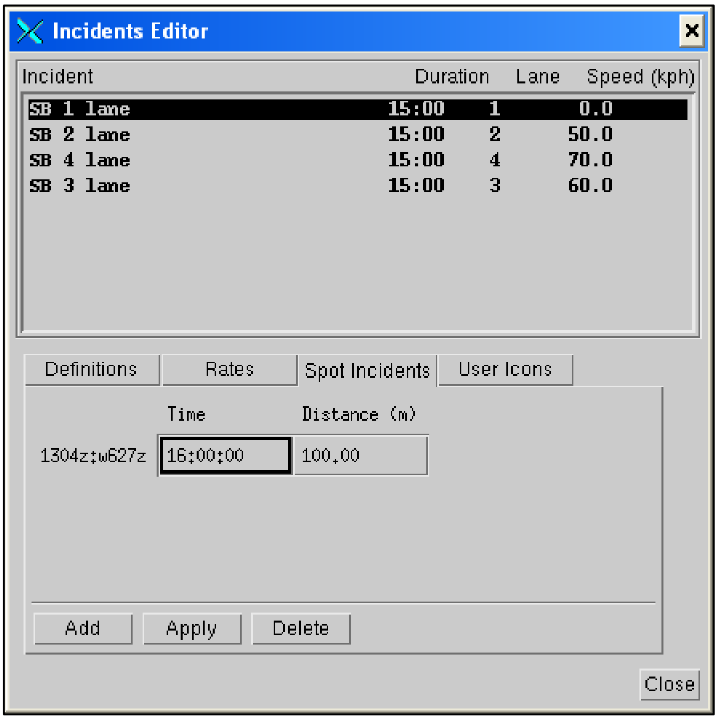
This incident reflected a partial reduction in capacity, as might be expected following a motor vehicle breakdown. Adjacent lanes have also been slowed down to reflect the typical reduction in capacity experienced due to less optimal road conditions and driver “rubber-necking”.

The incident was located on the southbound lanes of SH1 just south of the Northcote off ramp (in a similar location to the known incident); see the location in Figure 7. There are three general traffic lanes, together with a hard shoulder that Is not normally used for traffic. The following effects were modelled on the relevant lanes:

• Lane 1 (shoulder)	not available
• Lane 2	50km/h
• Lane 3	60km/h
• Lane 4 (median lane)	70km/h

The incident occurs at 16:00 and lasts 15 minutes (i.e. in the "shoulder" of the peak period). All of this information was conveyed to Paramics via its Incidents Editor, as shown in Figure 8.

Figure 8: Using the Incidents Editor in Paramics to model a Lane Closure



Incident	Duration	Lane	Speed (kph)
SB 1 lane	15:00	1	0.0
SB 2 lane	15:00	2	50.0
SB 4 lane	15:00	4	70.0
SB 3 lane	15:00	3	60.0

	Time	Distance (m)
1304z:w627z	16:00:00	100.00

3.4.2.2 Arterial Incident

This incident occurs immediately east of the motorway on the westbound lanes of Northcote Rd (i.e. approaching the motorway interchange); see the location on Figure 7. The kerb lane was closed (e.g. due to a minor accident), and the second (median) lane had speeds reduced to 30km/h (probably due to rubber-necking).

As with the motorway incident, the incident occurs at 16:00 and lasts 15 minutes (i.e. during the shoulder of the peak period). This relatively short duration allows the model to determine the time for the network to recover following the incident.

3.4.3 Calibration

One of the objectives of this research is to investigate model calibration for incident conditions. As stated in section 3.3, the base model calibration was not ideal due to the size and complexity of combining two already large models. As part of the base calibration (as described in Appendix A), many fixed routes were created to avoid vehicles incorrectly re-routing. However, these fixed routes had to be removed to allow re-routing to occur in the known incident model. As a result, the calibration of the known incident was not possible. New fixed routes would need to be created in order to obtain a proper calibration.

Traffic models would not normally be calibrated against an “abnormal” situation like a network incident; it is likely that some of the default behavioural aspects of driver behaviour are less relevant during such a situation. Nevertheless, there is some interest in this issue, to assist with planning of evacuations from areas with approaching natural hazards (e.g. hurricanes and tsunamis).

For example, Dixit *et al* (2011) developed a TRANSIMS model to reflect transport patterns around New Orleans during a mass evacuation and used historical data of such an event to calibrate the model. In comparing observed versus modelled data, they considered a range of measures to check model accuracy, e.g. GEH statistic, U-statistic, mean squared error. They settled on using regression analysis (i.e. fitting to y=x for observed vs modelled) because it does not assume independence among volumes observed at subsequent time intervals and is not overly sensitive to small variations likely to be found in a large-scale model. Although the r^2 values for individual hourly volume comparisons ranged between 0.21 and 0.76 for individual directions of evacuation, the *cumulative* volumes in each direction all had r^2 values ≥ 0.94.

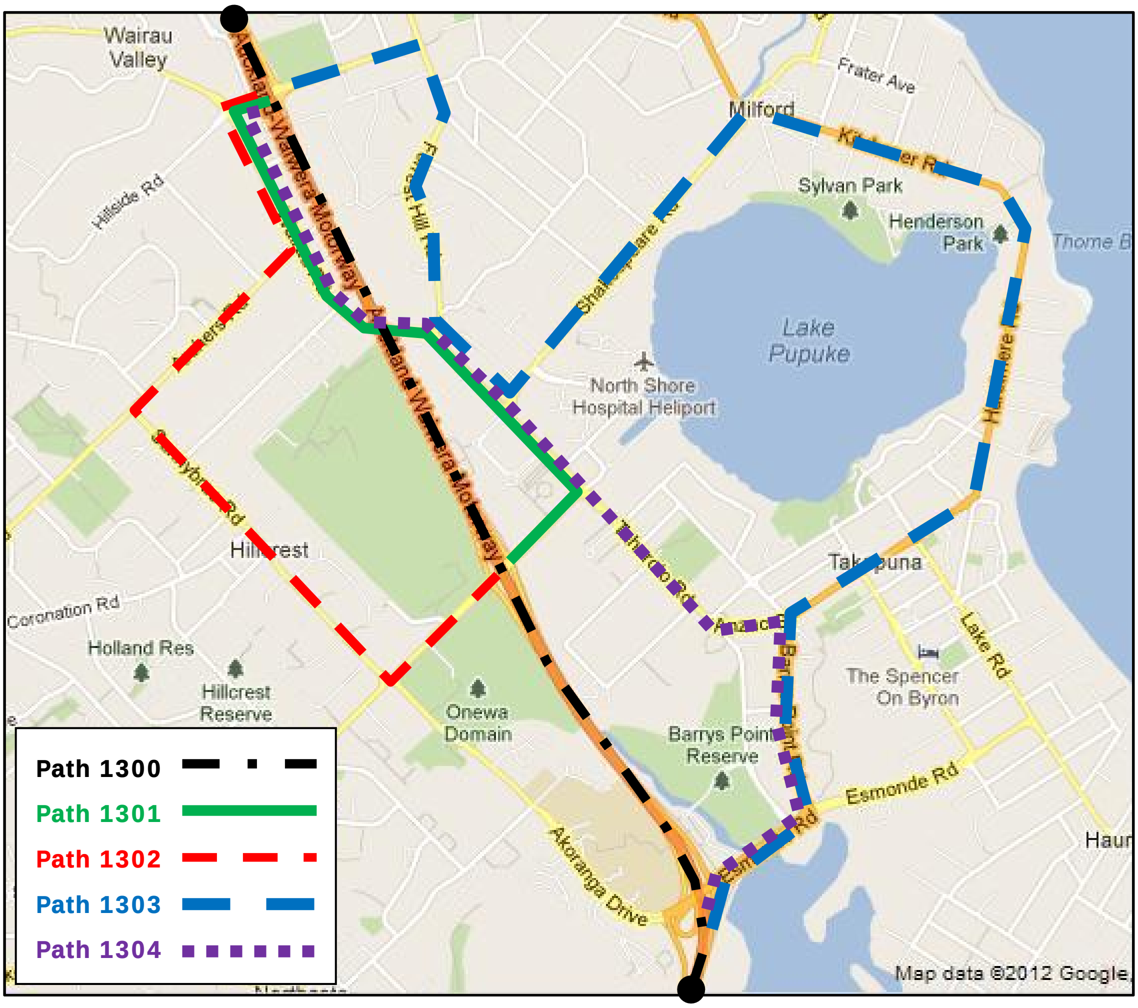
3.4.4 Diversion Rates

The scenarios modelled in this study lend themselves to a number of potential diversion routes away from the incident. Figure 9 shows some of the most likely routes should an incident happen near the Northcote interchange; southbound motorway traffic may exit further north (e.g. Tristram or even Constellation interchanges) to use the arterial road network and then rejoin the motorway later on. Alternatively, they may stay on their original route down the motorway.

In the actual known incident, VMS messages were displayed to inform approaching motorists of the incident. The effect of VMS on traffic using various off-ramps can be discerned from SCATS® detector data. Unfortunately the main-line (motorway) volumes at the time were not recorded, as detectors were out of action due to busway works. However using historical main-line data, an estimate can be made. Alternatively, a comparison can be made of “typical” off-ramp flows at the same location a week earlier or later, to see how they differ.

It is important to identify the preferred detour routes and to promote and optimise these routes by means of SCATS® control. Although modelling can help to determine the optimal routes (and Section 5 will further discuss how this might be undertaken), there may also be policy matters as well as technical reasons that go into the final decisions regarding detour routes.

Figure 9: Alternative Diversion Paths



3.5 Treatments used for this study

From the previous literature review, some potential treatments of the two hypothetical scenarios were considered for examination. The chosen treatments are discussed below; note that modelling difficulties limited the number of treatments that could ultimately be explored.

3.5.1 Constraints for this project

It was not possible to get the unusual congestion monitor (described in Section 2.2.1) to run in the modelled environment. The problem is that the unusual congestion monitor relies on historical information that it records over weeks to determine what is “usual” congestion. This was not possible to capture in the model environment.

The version of SCATS® used in the model is version 6.5.2. Therefore, Variation Routine VR83 (described in Section 2.2.2) could not be tested, as it was introduced in version 6.6.2.

3.5.2 Treatments for Motorway Incident

For the motorway incident, additional capacity was provided by allowing traffic to run on the motorway shoulder as an additional lane (often known as "hard shoulder running", see Bhouri & Aron 2013, Geistefeldt 2012). This somewhat compensates for the reduction in total available capacity along the corridor, although the physical attributes of the shoulder (particularly its constrained cross-section) may mean that it can't fully replicate the capacity observed from a normal traffic lane.

3.5.3 Treatments for Arterial Incident

For the arterial incident, SCATS® "Action lists" (as discussed in Section 2.2.3) were considered, to optimise diversion routes. Key diversion routes promoted are shown in Figure 9. Various actions were introduced to optimise travel along these routes, including:

- Using SCATS® Variation Routine VR67 to test for DS on Strategic Approaches
- "Trimming" (modifying) signal cycle lengths
- Trimming the "split plan", i.e. the arrangement and timing of signal phases
- Creating a "marriage" (i.e. coordinated link) between adjacent intersection sub-systems, to allow for "green waves" of traffic

The aim was to produce a traffic signal scheme that was optimised for arterial road traffic travelling *parallel* to the motorway rather than across it.

4 Modelling Results

The following sections outline observed results from both the collected field data and the simulated incident models.

4.1 Known Incident

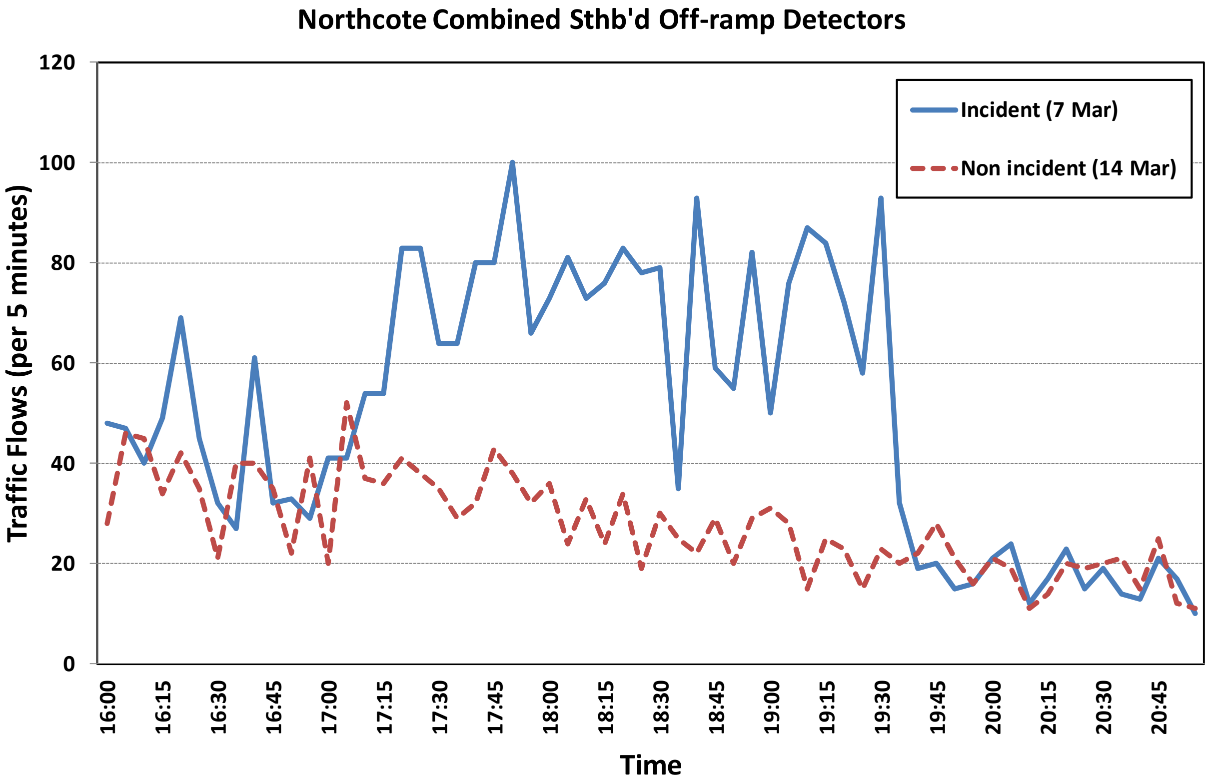
Figure 10 shows the layout of the Northcote Interchange, including the location of the various SCATS® detectors (numbers shown in rectangles). It can be seen that southbound traffic diverting off the motorway at this interchange would trigger either detectors 5 or 6. Therefore data was collated from the SCATS® records for these two detectors to investigate the effect of the known incident on diversion rates. A similar exercise was undertaken at the upstream Tristram Interchange.

Figure 10: Northcote Interchange and SCATS® Detector Layout

4.1.1 Diversion Rates

Figure 11 shows the observed traffic flows (at 5-minute intervals) across the Northcote off-ramp detectors on the day of the known incident and the same time period exactly one week later. It is clear that additional traffic was using the off-ramp on the day of the incident between approximately 17:15 and 19:30. Interestingly, there is no clear delineation of flows after 17:50 when the motorway was fully closed.

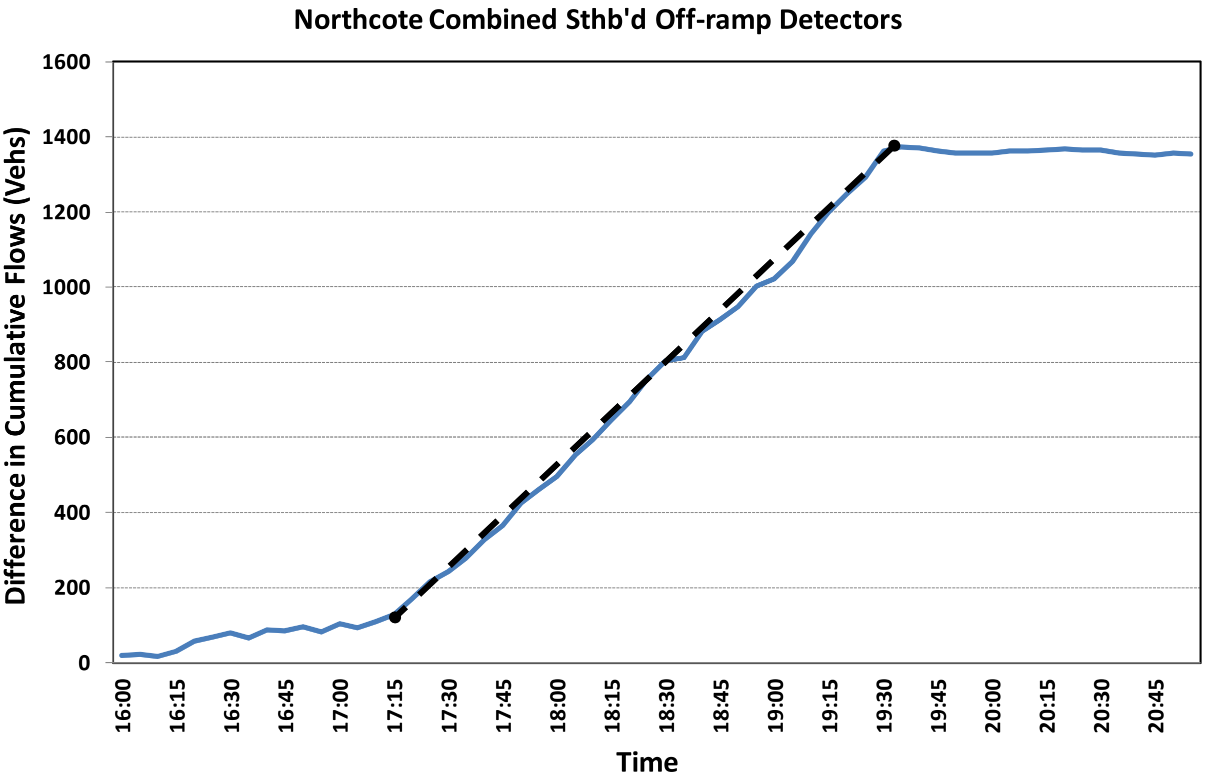
Figure 11: Northcote Interchange – Comparison of Incident/Non-Incident Traffic Flows



Note that it is probably more ideal to apply a comparison of the incident against a true average of "normal" flows from a larger sample of other weeks. This would help to counter any concerns that the chosen week was not actually sufficiently representative of "normal" flow conditions.

The ever-varying nature of the traffic flows shown in Figure 11 can make it hard to discern exactly when the traffic pattern changed. Therefore, an alternative analysis was undertaken using the cumulative totals of traffic on each day; Figure 12 shows the difference between the two respective cumulative totals as the evening went on. Although a little bit of difference in flows was evident before 17:15, it is clear that something more dramatic happened after that, causing the difference in flows to total over 1000 vehicles during the ensuing couple of hours. The dashed line indicates the approximate period of this growth. Again, the end point is very obvious, with a clear flattening of the difference after 19:30 (when the motorway was fully re-opened). This highlights the usefulness of cumulative plots when traffic flows are naturally varying from one time interval to the next (as is often the case in stop-start congested traffic).

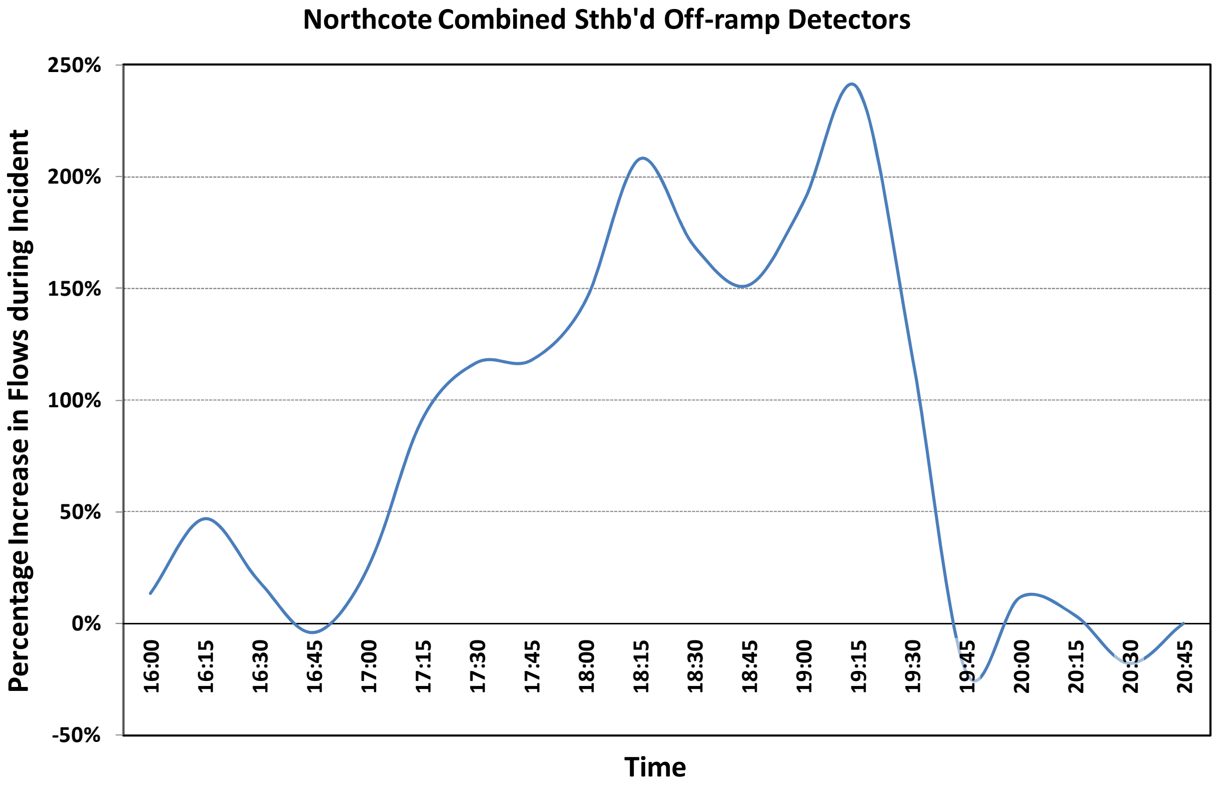
Figure 12: Northcote Interchange – Cumulative Difference in Incident/Non-Incident Traffic Flows



Another way of looking at the effect of the incident is compare the off-ramp flows during the incident as a percentage of the equivalent non-incident flows. Figure 13 shows such a plot; using 15-minute intervals this time to smooth out the variations in 5-minute periods. It can be seen that there was an approximate doubling of off-ramp flows from ~17:15 during the incident (i.e. ~100% increase) and then climbed to about a 200% increase once traffic was fully diverted.

Note that this doesn't mean that the main-line flow is normally approximately twice that of the off-ramp flows (because it was all diverted). Such a conclusion would fail to take into account the effect of normal main-line traffic that has been diverted earlier upstream. In fact, normally at the Northcote Interchange, the main-line flow is ~5.0 times that of the off-ramp flow.

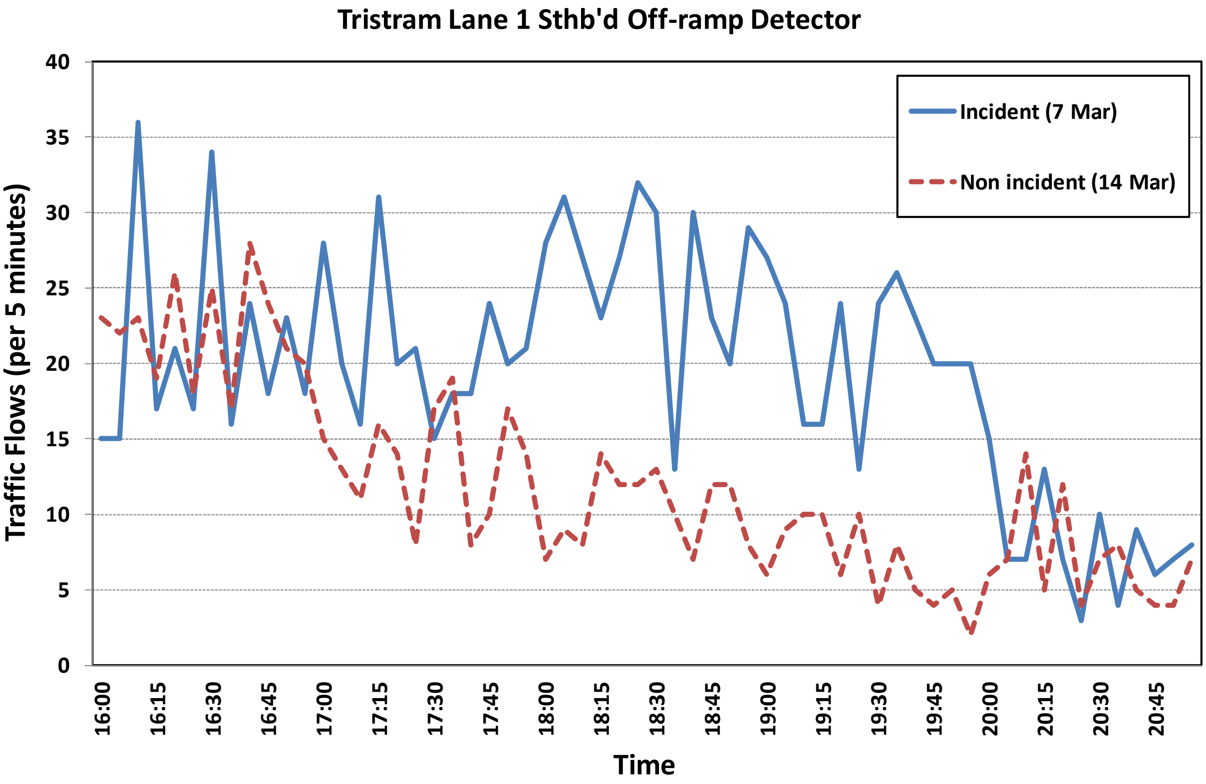
Figure 13: Northcote Interchange – Percentage Difference in Incident/Non-Incident Traffic Flows



A similar analysis could be undertaken at the adjacent upstream interchanges. Given that VMS was deployed at the Tristram Interchange encouraging traffic to divert, the effect of this intervention can be assessed. Unfortunately one of the two loop detectors at the Tristram off-ramp was not working and thus only an approximate effect can be compared.

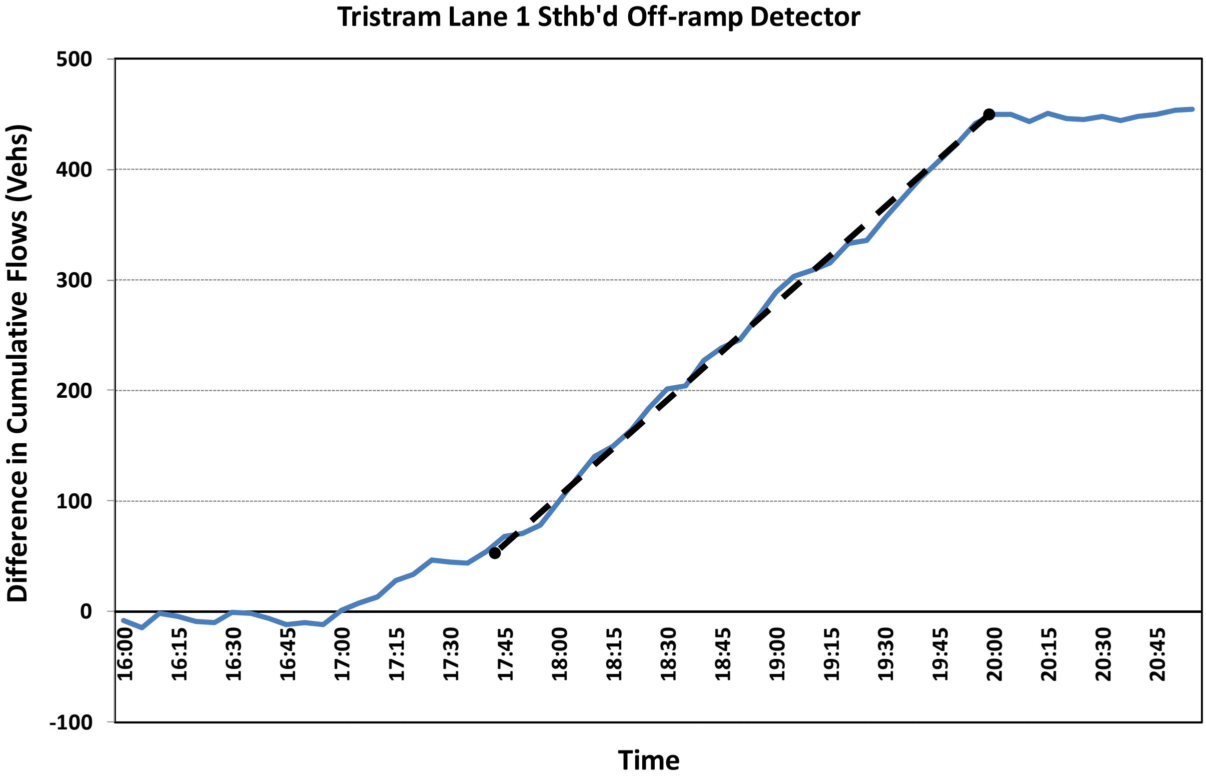
Figure 14 shows the respective off-ramp flows at the Tristram Interchange during the incident and non-incident periods. Again, there is a reasonable indication that some increase in flows was apparent following the incident at Northcote, although there is a bit of a lag in when it appears and subsides.

Figure 14: Tristram Interchange – Comparison of Incident/Non-Incident Traffic Flows



As with before, to reduce the distraction of the 5-minute variations in flow, a cumulative analysis can be undertaken. Figure 15 shows this plot for the Tristram Interchange. Although there is some growth in the difference from ~17:00 onwards, there is a clear steepening of the cumulative difference from ~17:45 (as shown by the dashed line) through to ~20:00. This suggests an approximate 30-minute lag in the effects of Northcote Interchange reaching Tristram. Given that the two interchanges are 2.0 km apart, this suggests a queue progression rate of ~4km/h or ~65m per minute. Alternatively it may simply reflect when the VMS display at Tristram started to influence drivers to divert early.

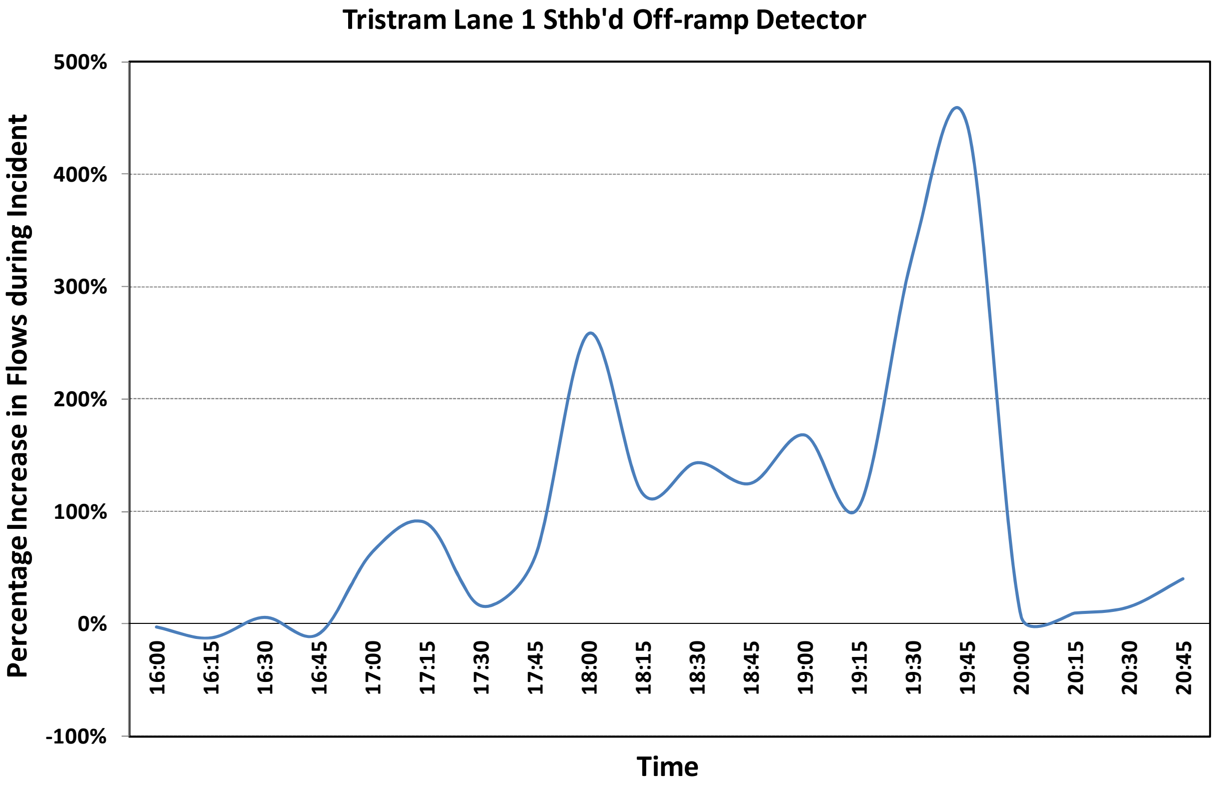
Figure 15: Tristram Interchange – Cumulative Difference in Incident/Non-Incident Traffic Flows



Again, a percentage comparison can be made between the incident and non-incident off-ramp flows. Figure 16 shows the differences for the Tristram Interchange. For most of the time, off-ramp flows increased by ~150% but there is a late surge to over 300% for the last half-hour before 20:00.

Given that the Tristram main-line traffic flows are normally ~5.0 times the off-ramp flows, a 150% average increase in off-ramp flows would suggest a diversion rate due to the VMS of ~30% (1.5/5.0). However the actual rate may be even higher if additional traffic has diverted further upstream (or chosen not to take this route due to the incident). Analysis of the next upstream interchange (Constellation) certainly suggests further increases in off-ramp flows there compared with normal non-incident flows, most of it not starting until ~18:30.

Figure 16: Tristram Interchange – Percentage Difference in Incident/Non-Incident Traffic Flows



4.2 Hypothetical Incidents

The following tables present the summary results from the model runs of the two hypothetical incidents created, both with and without the planned treatments. In all cases, five model simulations were run (with different random seeds) to assess the level of variation inherent in the situation; however one simulation run had to be discarded for the arterial treatment case.

4.2.1 Motorway Incident Results

Table 4.1 summarises the key results from the models simulating a breakdown on the motorway (“Incident”) and the effects of implementing hard-shoulder running of traffic to alleviate this (“Treatment”).

Table 4.1 **Summary of overall statistics from motorway incident models**

Scenario	Total Number Vehicles Modelled	Average Travel Time (s)	Range of Travel times *{and standard deviation}* (s)	Total Distance Travelled (km)	Total network travel time (hrs)	Mean Travel Speed (km/h)
Incident	75,268	610	461 – 750 *{126}*	293,073	12,621	23.9
Treatment	79,173	487	453 – 512 *{25}*	319,217	10,706	29.9

It should be noted that the average numbers of vehicles modelled differ quite substantially between the two scenarios. This reflects the fact that, in the base incident case, not all of the traffic demand modelled could be loaded onto the network, due to serious congestion.

That aside, clearly the treatment was successful in dramatically improving the average travel times for traffic, and thus increasing the corresponding mean travel speeds. The mitigation was estimated to produce a 25% increase in average speed across the entire network and a 9% increase in the average trip distance, giving a 20% reduction in the trip times. Note that, even with more vehicles, the total network travel time decreased in the treatment scenario. Arguably of more significance was the considerable reduction in the variability of average travel times, with the standard deviation reducing by ~80%.

Average network data may mask significant changes for better or worse in specific journey paths; indeed, there may be some parts of the modelled network largely unaffected by the changes near the incident location. To help investigate this further, more detailed analysis of journey data along specific diversion routes (as outlined in Figure 9) has been collated and summarised in Table 4.2.

Table 4.2 **Specific diversion path data from motorway incident models**

Paths	Average Path Length (m)	Incident		Treatment		Percentage Improvement in Travel Time (%)
		Average Journey Duration (s)	Average Travel Speed (km/h)	Average Journey Duration (s)	Average Travel Speed (km/h)	
Path 1300	6484	303	77.0	295	79.1	**2.6%**
Path 1301	7107	656	39.0	620	41.3	**5.5%**
Path 1302	8118	676	43.2	665	44.0	**1.7%**
Path 1303	11187	1306	30.8	1219	33.0	**6.7%**
Path 1304	7239	818	31.9	768	33.9	**6.1%**

It is interesting to note that, despite the incident on the motorway, the average time if staying on the motorway (path 1300) is still considerably better than the alternatives that divert onto adjacent arterial routes. It may be that the scenario tested was not sufficiently "serious" enough to fully test the benefits of encouraging route diversions. Nevertheless, applying the shoulder-lane treatment generally resulted in considerably more improvement to the travel times and speeds along these arterial routes than to the motorway itself, varying from about 2% to 7%. This illustrates the extent to which an isolated incident can affect the surrounding network.

4.2.2 Arterial Incident Results

Table 4.3 summarises the key results from the models simulating a kerb-lane closure on an arterial road near the motorway ("Incident") and the effects of implementing a revised SCATS® action plan to alleviate this ("Treatment").

Table 4.3 Summary of overall statistics from arterial incident models

Scenario	Total Number Vehicles Modelled	Average Travel Time (s)	Range of Travel times *{and standard deviation}* (s)	Total Distance Travelled (km)	Total network travel time (hrs)	Mean Travel Speed (km/h)
Incident	78,559	499	430 – 593 *{71}*	314,401	10,871	29.4
Treatment	78,745	490	459 – 556 *{39}*	316,371	10,706	29.7

This time, the improvement in average travel times and mean speeds is less significant (between 1% and 2%), also reflected in the relatively small change in vehicles loaded onto the model. However, again the variability of average travel times is significantly reduced, with a reduction of 45% observed.

Again, more detailed analysis of journey data along specific diversion routes from the motorway has been collated and summarised in Table 4.4.

Table 4.4 Specific diversion path data from arterial incident models

Paths	Average Path Length (m)	Incident		Treatment		Percentage Improvement in Travel Time (%)
		Average Journey Duration (s)	Average Travel Speed (km/h)	Average Journey Duration (s)	Average Travel Speed (km/h)	
Path 1300	6484	296	78.8	291	80.1	**1.7%**
Path 1301	7107	663	38.6	583	43.9	**12.1%**
Path 1302	8118	664	44.0	643	45.5	**3.2%**
Path 1303	11187	1208	33.3	1219	33.0	**-0.9%**
Path 1304	7239	751	34.7	771	33.8	**-2.7%**

As might be expected, given the location of the incident this time, there is little difference in travel times/speeds along the motorway route (path 1300). The results for the alternative routes were mixed, with some improving as a result of the SCATS® treatment, and some getting slightly worse. This illustrates the fact that a targeted SCATS® plan to optimise certain diversion routes may produce "winners and losers", depending on which alternative routes are optimised.

4.3 Discussion of Results

As with the earlier Stage 1 research, the results demonstrate the potential for targeted treatments to be able to influence the effects of incidents on road users. Equally importantly, various means were identified for being able to *quantify* the effectiveness of these treatments, using either available field data (such as SCATS® detector loop counts) or modelled simulation results.

VMS displays were shown to have some influence on diversion rates at off-ramps. One suspects that this was also influenced by the presence of visible queues ahead of motorists, which validated the message that the VMS was communicating. It would be interesting to investigate further how much of a difference a visual cue like this has on the effectiveness of such VMS messages.

Hard shoulder running is a promising technique that may provide quite substantial performance gains when main-line capacity is temporarily reduced, for relatively little investment. The safety aspects of eliminating the shoulder "buffer" need to be considered further, although overseas literature looks promising on that front too.

There will still be plenty of situations where infrastructure-based solutions like VMS and hard shoulders will not be readily available. Therefore it is expected that implementing targeted changes to SCATS® signal plans (e.g. to prioritise alternative diversion routes) will continue to be a key treatment for many incident scenarios.

The modelled hypothetical scenarios demonstrated that one of the biggest benefits of introducing many incident treatments may be to greatly reduce the average variability in travel times, even if the mean travel times don't change greatly. Given that other research has identified this as a very strong part of how road users perceive network performance (e.g. Ensor 2004, FHWA 2006), it seems imperative that some measure of this variability is included in any performance measures used to assess different incident treatment options.

5 A Template for Evaluating Incident Management Strategies

The above modelling tasks highlight the complexities of investigating scenarios involving the effective identification and treatment of unplanned incidents. Pre-determined incident management plans may be a way to improve the default handling of such situations; these would (for example) identify key alternative routes, provide signal priority along these corridors, and possibly provide driver guidance using dynamic signage and in-vehicle navigation systems. Modelling such scenarios can determine how effective they are relative to other options.

A risk identified at the start of this project was that investigation of specific case studies may produce solutions that are only pertinent to that particular situation and not widely applicable elsewhere. While (to a certain degree) this is always the case, the aim was to endeavour to infer general conclusions based on observed trends across a number of different test cases, and from the literature review.

Ultimately, for a large complex network, it may require a considerably large selection of management plans to be developed to cover the range of incidents that may occur (particularly with regard to location). The biggest difficulty will probably be in determining the most suitable (or a sufficiently suitable) treatment for the particular incident being considered. There are a lot of different scenarios in many potential locations and treatments cannot be generalised for all scenarios.

One way to provide a way forward is to develop a standard “template” that can be applied to testing potential scenarios for a particular network being managed. This would provide a consistent process for identifying the most significant risks to a network, comparing the treatment options, and developing suitable contingency management plans. This section discusses the key tasks involved in developing such a template.

5.1 Suitability of situations for developing management plans

It is important to appreciate that incident management plans may be limited in how effectively they can improve a given situation for the network as a whole. Typically, an incident does something to reduce the capacity of the existing network, and if that network was already very close to capacity (or indeed over-capacity during peak periods) then no amount of “tinkering” may provide any tangible improvement until the demand goes down and/or the reduced capacity is returned. Indeed, simply informing people by various means *not* to travel during this period, or to make a very wide detour around the problem area, may be the only practical steps available.

Some consideration to the number of available alternative routes is also needed. Firstly there has to be a credible alternative route for (at least some) traffic to divert to; fortunately in most urban areas that is usually not a problem, but there may be occasional exceptions (for example, traffic between Petone and Ngauranga in Wellington currently doesn’t have an alternative traffic route without considerable detours). If there is no credible alternative then, again, the only management plan that can be applied is to inform people not to travel and to attempt to reinstate the reduced capacity as soon as possible. At the other end of the spectrum, a network with many reasonable alternative routes may not require a specific management plan if traffic can fairly easily redistribute amongst the alternatives; it may also be harder to narrow down the best alternative routes to optimise and promote if travellers have many different alternative origins and destinations.

Koorey & Mitchell (2000) considered the effect of link reliability when evaluating physical improvements to a road network and concluded that it is generally sufficient to only consider network reliability for links where there are **two or fewer** "alternative routes". However this study was largely focused on situations where complete closure of links had occurred (e.g. bridge washout) and maintaining some network connectivity was more important than the additional travel time incurred. In the context of this current study, a more appropriate recommendation might be to limit the number of alternative priority route options *investigated* to no more than two.

The results from this study and elsewhere therefore highlight that incident management plans are most effective when:

- There are sufficient vehicles present to benefit from any plan implemented (and hence, justify the work required to develop the plan);
- There is at least one obvious diversion route; and
- There is sufficient *spare* capacity to enable diversion routes to work better than the original route.

In practice this typically means that periods on the shoulders of peak periods may be the times where incident management plans are most likely to generate sufficient benefits. Because traffic flows typically differ directionally in the morning and evening, at least two different shoulder period scenarios may need to be tested to develop management plans for each case (e.g. 9-10am and 4-5pm might be appropriate for a particular network).

As it happens, these shoulder periods may also produce some of the most serious crash incidents. Typical speed-volume relationships may mean, for example, that low-speed near-capacity situations (as likely to be found during peak periods) are not as hazardous as higher-speed medium flow situations (as found during the shoulder periods). Therefore, a crash during a shoulder period may be more likely to create significant disruption during the aftermath.

5.2 Identifying Critical Locations

Classic risk analysis considers both the *likelihood* and *consequences* of a particular hazard occurring, and this seems like a sound approach to assist in the identification of locations warranting incident management planning.

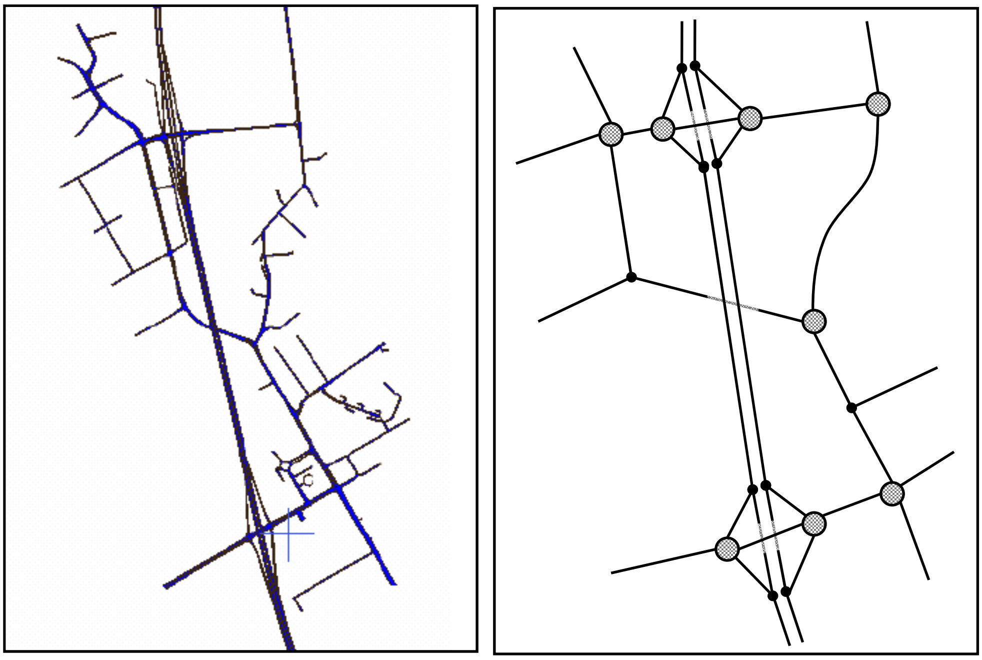
5.2.1 Identifying Network Links

To simplify the analysis problem, the network being studied should be divided into road link sections between major "nodes" (intersections, on/off-ramps, etc). For example, if there are 2km of motorway between adjacent interchanges, then it is largely irrelevant where exactly in this section an incident occurs; the alternative route choices for upstream traffic are generally the same. Hence, such a length should be considered as a single link section. Roads with separate carriageways in each direction would be considered as two separate link sections.

For major at-grade intersections, it might be appropriate in some cases to consider the intersection itself as a "section" that could be closed or have reduced capacity, with obvious implications for the connecting road links. Historical incident or crash data may be able to provide guidance on which intersections should be treated as such.

Figure 17 provides a hypothetical example of how this could be applied to an area. The more detailed modelled network has been simplified into a smaller number of link sections (between node points), as well as a number of major intersections (large grey nodes) that may also warrant testing for their effect on the network. This greatly reduces the analysis problem in terms of components to be checked.

Figure 17: Example of how a modelled network might be converted in link sections



If necessary, a simplified network could be explored in more detail later as required. For example, if the curving link in the top-right of Figure 17 was found to have a very critical effect on network performance, it could be later broken up into smaller sections between intermediate intersections and re-analysed, to zero in on the potential effect of localised closures and detours.

5.2.2 Most Likely Incident Locations

Potentially *any* vehicle on the network could be involved in an incident such as a crash or breakdown. In terms of breakdowns, the likelihood would be approximately related simply to the volumes of traffic present in different locations. However that may also have to be modified to consider locations that can cause greater strain on a typical vehicle, most notably significant grades.

Crashes are more likely to be influenced by the road environment itself; hence intersections (and approaching traffic in queues) invariably have a higher risk. Other locations where complex manoeuvres are present, such as merging and weaving, would also have a higher risk of a collision. Higher-speed locations with poor geometry may also produce a disproportionately higher number of crashes.

Guidance on where to focus attention may be best done on the basis of historical records of similar incidents. Crash data, for example (both self-maintained and Police-reported), may provide a useful indicator of high-risk locations. It should be remembered however that low-severity but disruptive crashes such as rear-ends may not be reported to Police with the same likelihood as more serious high-speed and intersection incidents. Hence, network management records of incidents (perhaps maintained by network contractors) may be of more value, with the added advantage that they will probably also include other events such as breakdowns. If the data also records the approximate time for each incident from notification to clearance, then an approximate tally of “incident-hours per year” can be determined for each link.

5.2.3 Incident Locations with the Greatest Consequences

In a complex road network it can be difficult to readily identify the links that may cause the most disruption to the overall traffic performance. This is where preliminary modelling may be able to assist with such identification. Such a process would involve systematically removing (or at least reducing the capacity of) different key links one at a time from the base modelled network, and then returning them and trying another link.

For each link removed, the relative increase in network travel time NTT (compared to the base case) can be calculated (other network performance measures could be considered, although NTT is probably the most useful). This will determine which road links are the most disruptive to the network as a whole when not available.

The overall “riskiness” of each link can then be ascertained by combining the results from the likelihood and consequences assessments, i.e.

{Relative risk of link n} = {Ave. incident-hrs/yr for link n} × {Relative increase in NTT without link n}

Because this is an exercise in relativities, time-consuming calibration of the network with each change should not be necessary. The aim is to identify reasonably quickly the top links to focus efforts on developing management plans for; how many locations to investigate will ultimately depend on the available modelling and staff resources.

In some situations, the assessment of consequences may be limited to only parts of the network. For example, there may be a particular area of town quite sensitive to increases in congestion (e.g. tourist precinct), there may be a desire to minimise delays to traffic originally on the State Highway network (even at a cost to other local road traffic). So long as the modelling software is able to extract the necessary travel results for a subset of the whole data, the process shouldn’t be too dissimilar.

Notwithstanding the above objective method for testing link criticality, there are some general rules of thumb about which link sections are most likely to be critical:

- Locations of greatest demand for traffic (i.e. highest mid-block volumes or intersection throughput)
- Sections with few alternative routes on either the arterial or local roading networks.

5.3 Testing Different Management Treatments

Having identified the network locations where incidents have the greatest effect, consideration can now be given to testing some potential treatments. As identified in the previous study (Koorey *et al* 2008), a number of potential treatments may be appropriate, including:

- Changing SCATS® signal timing plans so that alternative detour routes are given greater priority
- Limiting additional vehicles into the incident-affected section, e.g. via ramp metering or reduced signal phases in that direction
- Providing driver information (e.g. through dynamic VMS signage or in-car navigation), advising motorists of the incident and suggested detours
- Providing traveller information (e.g. via websites or radio), advising people not to travel or to avoid a certain area (i.e. reducing the traffic demand temporarily)
- Temporarily reallocating roadway space, e.g. allowing shoulder or bus-lane use by general traffic, or reassigning variable traffic lanes
- Responding to the incident more quickly (e.g. greater deployment of breakdown vehicles around the network) and reducing the time that the affected section has reduced capacity

All of these options can be compared against the default situation, typically where the existing SCATS®-controlled network automatically adjust to the new situation by itself. Ranking of the options can be done in terms of changes to overall network travel time, although some consideration might need to be given to ensuring that there are no unduly adverse effects from any option on a sub-section of the network or travellers.

Obviously which treatment options are explored will depend somewhat on the available facilities. For example, use of a shoulder-lane is only an option for road links where there is a continuous shoulder available (and ideally some kind of lane-use signage); typically this would only be appropriate on motorways. Driver information may also not be useful in locations where the approach roads have no dynamic VMS; although one contingency plan could be to place a mobile VMS in appropriate locations.

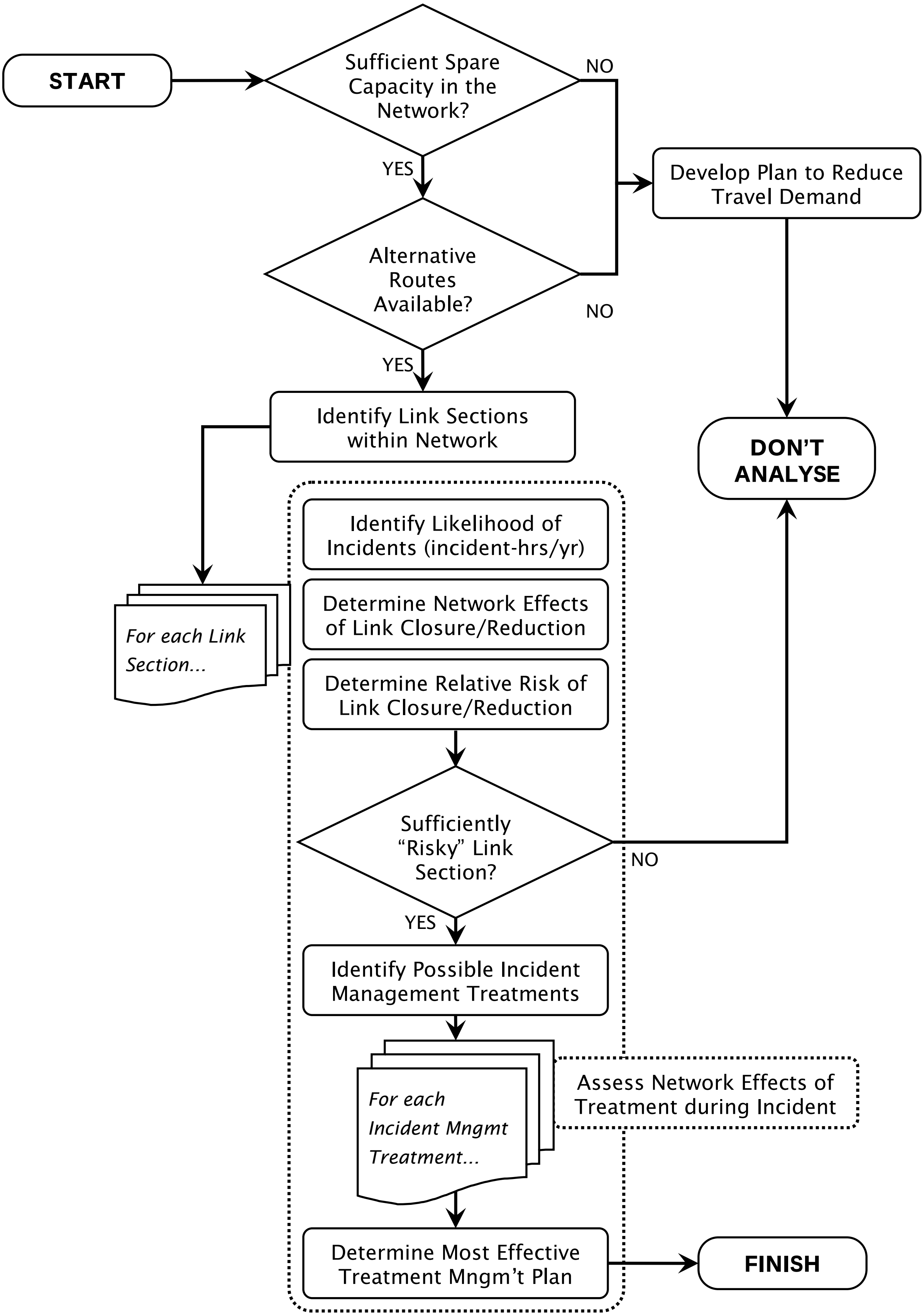
In other cases, there may be multiple alternatives that could be tested; for example, which diversion route to prioritise. As with other options, this may simply be a case of testing each one and determining which alternative produces the least disruption overall (i.e. lowest NTT), without creating huge inequities in delay.

5.4 Summary of Template Process

The above steps can be summarised using the following process chart in Figure 18. This provides a methodical framework for determining the most critical incident situations in a network and the most effective treatment options to apply to these incidents.

Further discussion of aspects to be considered as part of a specific incident management plan can be found in the Stage 1 report (Koorey *et al* 2008).

Figure 18: Process for Developing Incident Management Plans



6 Conclusions

A literature review and series of micro-simulation models of incidents in a New Zealand urban network found that:

- Both simulation modelling and collection of actual field data have valuable roles in understanding incident management behaviour.
- A simple measure of" diversion rate", based on the ratio of main-line and off-ramp traffic flows, can help to identify how many vehicles might be influenced by either VMS displays or visible signs of queuing ahead. This can be assessed using either modelled or observed data.
- Cumulative measures of traffic flow during similar incident and non-incident periods can also be used to ascertain the total number of vehicles diverted rather than simply delayed. This approach also helps to avoid the difficulty of comparing short time-intervals with varying traffic flows
- Analysis of data relating to changes in traffic flows following an actual incident on the motorway found diversion rates of at least 30% to upstream off-ramps when appropriate messages were communicated via VMS.
- Hard shoulder running is a promising technique that may provide quite substantial performance gains when main-line capacity is temporarily reduced, for relatively little investment. Modelling such a treatment after an incident was estimated to produce a 20% reduction in the trip times across the entire network, although the estimated effect on some selected diversion routes was much less, varying from about 2% to 7%. However, the reduction in the standard deviation of trip times was much larger, being about 80%. The safety aspects of eliminating the shoulder "buffer" need to be considered further, although overseas literature looks promising on that front too.
- SCATS® has a range of tools that can assist with both the detection and treatment of incidents on road networks. While sometimes the absolute average time savings may be minimal, there is likely to be a greater reduction in variability of travel times when targeted SCATS® action plans are used to treat incidents. For a modelled arterial road lane closure, the mitigation was estimated to produce improvements in average travel times between 1% and 2%, although again the standard deviation reduced quite notably by ~45%.

The research has highlighted the complexities involved in identifying effective treatments for mitigating the effects of incidents. While specific case studies may produce solutions that are effective in particular situations, they might not be nearly as effective in other situations. For a large complex network, it may be necessary to have a large number of incident management plans, to cover the range of incident scenarios that might occur. Therefore, a 'template' has been developed for a consistent process for identifying the most significant risks to a network, comparing the treatment options, and developing suitable contingency management plans.

7 Recommendations

The following items are recommended for further investigation or action:

- Due to difficulties with some of the modelling tasks (e.g. calibration), not all of the desired scenarios and treatments were able to be tested in this research. Therefore, further modelling of scenarios using this network would be of great value. This includes further validation against known actual incidents where comprehensive traffic and incident management data is available.
- Consideration should also be given to developing some simplistic theoretical networks to test out some aspects of incident management, such as the effect of providing additional alternative routes, the consequences of adjusting incident response times, and the merits of different network performance measures.
- The relative benefits to be gained by introducing hard shoulder running when main-line capacity is temporarily reduced should be investigated. This should include consideration of the safety implications of eliminating the shoulder “buffer”.
- The template process proposed in this report should be trialled to develop suitable incident management plans for the major urban arterial road networks in New Zealand.

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9 Glossary

Adaptive signals	Traffic signals where the time allowed for each phase is dynamically determined from traffic conditions
Bluetooth	A wireless technology standard for exchanging data over short distances from devices such as smart phones
Capacity	The theoretical maximum sustainable volume of traffic that a particular road or intersection movement can accommodate
Cycle time/length	The time taken for a complete sequence of traffic signal phases to be run, before repeating
Degree of saturation	The ratio of the traffic demand (ie traffic volume or flow rate) to the theoretical capacity of the road or intersection
Detector	A sensing device (usually a loop of wire in the road) used to detect the presence of vehicles crossing or sitting at a location
DR	Diversion Rate; the proportion of vehicles that leave the main-line via some off-ramp or intersection to use an alternative route
FUSE	Software that links SCATS® to S-Paramics, developed by BasePLUS (NZ)
Incident	Some event (often unforeseen) that varies the normal travel pattern of a road, such as an accident, road works, or a vehicle breakdown. An incident may completely close off a road or just reduce its capacity
ITS	Intelligent transportation systems
Main-line	The main highway route being studied, from where traffic may divert off during an incident somewhere on that route
Microsimulation	Traffic modelling whereby individual vehicles are simulated within the road network and driver decisions are made dynamically in response to conditions encountered throughout the network
Paramics	See "S-Paramics" (as differentiated from "Q-Paramics" developed by Quadstone)
Peak period	The time of the day when traffic demand is at a maximum, e.g. morning and evening for commuter work trips. Other times are 'off-peak' periods
Phasing	A pre-set order of traffic signal phases and the time allocated to each one
RTA	Roads and Traffic Authority of New South Wales
SCATS®	Sydney Coordinated Adaptive Traffic System, an adaptive control traffic system, developed by RTA (Australia), that adjusts signal timing, phasing, offsets and cycle length according to actual traffic conditions in real-time. *Note that "SCATS" is a registered trade mark of the RTA in Australia and various other jurisdictions.*
Signal phase	A traffic signal state during which one or more vehicle movements receive right of way (i.e. green signal or arrow)
S-Paramics	Microsimulation software package developed by SIAS (Scotland)
Stop-line	A location right at an intersection where vehicles stop until they have right of way
Upstream	A location prior to the current location, i.e. from where a vehicle has come. A location beyond the current location is 'downstream'
VMS	Variable message signs

A Appendix A: Model Development and Calibration

A.1 Introduction

Aurecon were approached by the University of Canterbury to undertake the amalgamation and subsequent calibration of the existing Wairau-Taharoto Corridor (“Wairau Road”) and Takapuna S-Paramics models. The model was to be used to assess the ability of SCATS® to adapt to prevailing traffic conditions in response to a traffic incident within the model area. This section briefly outlines the creation and calibration of the combined model.

A.2 Wairau and Takapuna Traffic Models

Wairau Road Model

The Wairau Road model was constructed and calibrated by baseplus Ltd (now Aurecon) reflecting 2007 observed traffic survey data provided by North Shore City Council (NSCC). The purpose of the modelling was to assess resource consents in addition to future infrastructure requirements.

Takapuna Model

The Takapuna model was built by NSCC and calibrated by them to the observed traffic survey data collected at the same time as that used for the Wairau Road model calibration. The purpose of this model was to assess the future traffic growth within the area in addition to assessing the impact of changes to the current car parking arrangements.

A.3 Model Amalgamation

The amalgamation of the Wairau Road and Takapuna models began with the movement of nodes to common coordinates. The models were joined at common points along Taharoto Road, SH1 and Akoranga Road. In addition, the model was expanded to include roads to the west of Wairau Road and east of the model extending Hurstmere Road and Kitchener Road north to join with Shakespeare Road, inclusive of five additional signalised intersections.

In order to simplify the model, a number of parameters such as profiles and demand matrices were rationalised, in particular those associated with carparks in the Takapuna model. Demand to carparks was established by creating an exclusive zone for each carpark and applying inbound/outbound flows to each zone based on five model runs. Buses were removed in a similar fashion through creating a separate vehicle type and basing demand on model runs.

Care was taken when combining the models so that consistency was maintained for the following parameters; vehicle types, categories, restrictions and signal mapping. In places minor adjustments have been made to ease integration between the two models, particularly at model joins.

A.4 Model Calibration

Calibration of the amalgamated model was undertaken on the evening peak period only, i.e. from 15:30 to 18:30 with a peak hour of 16:30 to 17:30. Calibration outputs showing the comparison of modelled turn and link count volumes against the observed can be provided on request.

Summaries of the model outputs against US DoT (2004) and NZTA (2010) calibration guidelines are presented in Table 9.1 and Table 9.2. Only those values highlighted in bold meet the specified calibration requirements.

Table 9.1: Comparison of Calibration Outputs against US DoT Guidelines

Criteria & Measures	**Calibration Acceptance Targets**	**Peak Hour**	**3-Hour**
Individual Link Flows			
Within 15%, for >2700 veh/h	>85% of cases	70%	45%
Within 15%, for 700 veh/h<Flow<2700 veh/h	>85 of cases	61%	51%
Within 100 veh/h, for Flow<700 veh/h	>85% of cases	67%	83%
Sum of All Link Flows	Within 5%	**-5%**	-6%
GEH < 5 for Individual Link Flows	>85% of cases	57%	48%
GEH for Sum of All Link Flows	GEH<4	20.79	32.11

Table 9.2: Comparison of Calibration Outputs against NZTA Guidelines

Criteria and Measures	**Calibration Acceptance Targets**	**Peak Hour**	**3-Hour**
Hourly Link Flow, Modelled Versus Observed			
Individual Link Volumes	+/-20%	% links within 20%	
	flows <99 vph	15%	5%
	100-199 vph	38%	67%
	200-499 vph	34%	50%
	500-999 vph	57%	44%
	flows >1,000 vph	76%	67%
	All	53%	57%
R^2 value for modelled versus observed flows for all individual links	>0.85	**0.957**	**0.963**
GEH statistic < 5.0 for individual link flows	>60% of cases	57%	48%
GEH statistic < 10.0 for individual link	>95% of cases	87%	74%

flows			
GEH statistic < 12.0 for individual link flows	100% of cases	91%	79%
Root-Mean-Square Error (RMSE) for entire network	<30%	**22%**	**21%**
Intersection Flows and Delays			
Modelled Turning Flows (>100 vph)	Within 30% of Obs	54%	55%

A.5 Model Use

As can be seen from the previous tables, there are a number of standard performance criteria in which this combined model does not fully meet the normally desired values. This reflects the sheer size/complexity of this modelled network, which made it difficult to calibrate under normal circumstances given the tight project deadlines. However, the model has been calibrated to a level appropriate for the proposed use, i.e. the testing of the adaptability of SCATS® in response to incidents on specific routes.

It is also important that, when testing of specific incident scenarios is undertaken, modellers are aware of the influence of vehicle restrictions on route choice, particularly in relation to SH1 traffic. Vehicles that exclusively use SH1 are restricted to using this route and if a scenario involves the complete closure of SH1 then changes will need to be made to restrictions in order to enable these vehicles to use alternate routes. Additionally there are some alternate routes that may not be able to be fully captured within the model bounds and may require changes to the demands to model appropriately, e.g. if SH1 were closed and the alternative was to use East Coast Road then demand bound for SH1 (Zone 1) may need to be shifted to East Coast Road (Zone 111).