Effectiveness of Variable Mandatory Speed Signs within the Wellington ATMS, New Zealand

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Abbreviations and Acronyms

AADT	Annual average daily traffic volume
AID	Automated Incident Detection
ATMS	Active Traffic Management System
ATTOMS	Auckland Transit Traffic Operation Monitoring System
Austroads	Association of Australian and New Zealand Road Transport and Traffic Authorities
CCTV	Closed Circuit Television
ITS	Intelligent Transport Systems
km/h	kilometres per hour
LCS	Lane Control Signs
m	metre
mm	millimetre
mph	miles per hour
MWH	MWH New Zealand Ltd
NATMS	Ngauranga Active Traffic Management System
PTZ	Pan Tilt Zoom
SH	State Highway
TMS	Traffic Monitoring System
Transfund	Transfund New Zealand
Transit	Transit New Zealand
TSM	Traffic Speed Measurement
VIP	Video Image Processor
VMS	Variable Message Signs
VMSS	Variable Mandatory Speed Signs
WATTS	Wide Area Traffic Telematics Server

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Executive Summary

Introduction

This research project attempted to quantify the effects of Variable Mandatory Speed Signs (VMSS) on road user behaviour on New Zealand roads. Over a period of 7 months in 2002 vehicle speeds were monitored during normal or incident-free conditions and at those times when the signs were activated to reflect a management plan introduced in response to a specific incident.

The VMSS are located within the Ngauranga Gorge just north of Wellington, New Zealand, on State Highway 1 (SH1). The VMSS are an important component of the Ngauranga Advanced Traffic Management System (NATMS) which is utilised for the control of traffic along a demanding section of SH1. The VMSS complement other Advanced Traffic Management System (ATMS) architecture including Variable Message Signs (VMS), Automatic Incident Detection (AID) Cameras, and Lane Closure Signs (LCS) which are all part of the strategy to detect and respond to incidents quickly, in order to minimise delay to road users.

Objective of the Research

The principal objective of the research was to ascertain how road users responded to varying VMSS corresponding to both normal (incident-free) conditions and those reflecting reductions in speed caused by incidents.

Speeds were determined by AID Cameras with the usual measures of mean, standard deviation and 85^{th} percentile speed being quantified. Of particular importance was the percentage of road users exceeding the displayed mandatory speed limit.

In addition, the research has looked at how vehicle speeds vary between adjacent detection zones at the *same* instant in time and how speed changes in *any one zone* during the course of an incident.

The amount of traffic selecting to divert because incidents occurred downstream of Ngauranga Gorge has also been quantified.

Data Collection Process

Speed data was collected on typical or normal days free from incidents to produce base profiles which showed how speed varied according to time of day. The following periods were used for preparation of the discrete speed profiles – one for each zone – for each time period.

Table 1 Time periods utilised for producing Speed Profiles.

Time Period	Monday-Thursday	Friday	Saturday	Sunday
00.00 – 07.00	✓	✓	One Single Profile (all day) per Zone	One Single Profile (all day) per Zone
07.00 – 10.00	✓	✓		
10.00 – 16.00	✓	✓		
16.00 – 19.00	✓	✓		
19.00 – 24.00	✓	✓		

Speed measurements were also acquired over a 7-month period (Feb-Aug 2002) to reflect road user behaviour during incidents.

Incidents were categorised by type: unplanned (crashes or breakdowns), roadworks, weather and others.

Summary of Results

Normal or 'Incident-Free' Days

Table 2 Measured speeds under normal conditions.

Measure	Posted Speed 80 km/h			
	Monday-Thursday	Friday	Saturday	Sunday
Mean	77.9 – 78.1	77.7 – 78.8	80.5 – 81.6	81.1 – 81.5
85th Percentile	89.0 – 90.0	89.0 – 90.0	91.0 – 95.0	91.0 – 94.0
% Exceeding Posted Speed	33.0 – 43.0	36.0 – 42.0	43.0 – 53.0	39.0 – 56.0

The results show a range of speeds reflecting travel in both directions, with southbound speeds marginally exceeding northbound speeds. Generally, weekend speeds were higher than weekdays, with non-compliance levels (i.e. with posted speed limit) also showing a similar trend.

Non-compliance investigations revealed that between 33% and 56% of road users exceeded the 80 km/h posted speed limit. Non-compliance rates for the 100 km/h posted speed limit were much lower, with 1.0% to 11.0% exceeding the speed limit.

Investigation of mean speeds by lane showed that the median lane had a mean recorded speed some 3.7 to 5.9 km/h higher than that of the adjacent lane, again for an 80 km/h posted speed.

Incident Characteristics

Of the 247 incidents which occurred during the 7-month period in 2002, 56% were weather related, 25% crashes and breakdowns, 18% roadworks, and 1% other.

Incidents were more likely to occur during winter months with levels of frequency double that of summer months.

Incident plans introduced in response to roadworks involved setting VMSS for the maximum duration of almost 5.5 hours over which 41% of the controlled area was affected.

The average duration of incidents involving crashes or breakdowns was only 0.6 hours (35 minutes) although they generally affected almost half of the NATMS controlled area (47%). Mean speeds observed during different types of incident are summarised in Table 3. Almost all of the mean speed values are in excess of the posted speed, which is clear evidence that road users find it inappropriate and/or difficult to comply with the posted speed limit and particularly those having lower speed settings.

Values of mean speed are only shown for those incidents where significant amounts of data have been acquired. Further values are given in Table 5.8 of the main report covering additional types of incident and posted speeds where sample sizes are much smaller.

Table 3 Mean recorded speeds by type of incident.

Incident Type		Lane	Posted Speed (km/h)			
			50	60	70	80
Roadworks	Northbound	1	63.0		73.4	
		2	57.9		70.5	
	Southbound	1			67.0	
		2			58.7	
Unplanned (Pre-April 2002)	Southbound	1		70.7		
		2		64.7		
Crash	Northbound	1		73.6		
		2		67.0		
	Southbound	1		47.3		
		2		51.5		
Breakdown	Northbound	1		72.3		
		2		68.8		
Wet Weather	Southbound	1				90.4
		2				88.2
All	**Northbound**	**1**	**63.3**	**66.8**	**73.5**	
		2	**60.6**	**62.9**	**70.6**	
	Southbound	**1**		**62.8**	**67.0**	**90.2**
		2		**61.9**	**58.7**	**87.9**

Speed Change within Individual Zones during an Incident

Speeds would appear to drop over the first 15 to 20 minutes of an incident at any affected individual zone with speeds then showing a marginal increase between 35 to 55 minutes. Once again, the 50 km/h restriction shows the greatest variability.

Longitudinal Speed Variation at Zones affected by an Incident

Within an area affected by an incident, there is a high variability in speed recorded over the first 750 m for zones affected by an incident. Beyond this, recorded speeds are relatively consistent with some increase at the point of exit.

Diversionary Effect arising from the Signing of an Incident

Measurements of traffic volume exiting at the Hutt Road off-ramp were recorded during normal and incident conditions.

Increased traffic volumes resulted during incidents, especially during weekday periods with the weighted average increase amounting to 40%.

Speed Changes during Wet Weather Incidents

The only occasions when normal speeds could be compared with incident speed constraints, were where 100 km/h zones had their VMSS reduced to 80 km/h due to inclement weather. Thus the 80 km/h incident speeds could be compared with neighbouring zones where 80 km/h signs were in force during both normal and incident conditions.

The findings were inconclusive but the effect of wet weather signing produced a fall of between 3.5 and 5.5 km/h over normal mean speed.

Compliance of Road Users to VMSS during Normal and Incident Conditions

Percentage values for exceeding the posted speed limits are indicated in Table 4. They are shown against speeds during normal conditions for comparison reasons.

Table 4 Percentage of road users exceeding posted speed limits.

Conditions	Normal Conditions		Incidents			
Speeds	80 km/h	100 km/h	50 km/h	60 km/h	70 km/h	80 km/h
Percentage Exceeding Posted Speed Limit	40 – 49	3 – 10	76 – 80	67	40 – 76	76 - 87

The numbers of vehicles exceeding the posted speed limits during incidents are very high and it is clear that road users are largely ignoring posted speeds selected for the management of incidents. This is particularly evident at "low speed" incidents (50 and 60 km/h).

Differences between Speeds in different Lanes during Incidents

The speed data collected during incidents show a tendency to be skewed and to not follow a conventional normal distribution.

Consequently non-parametric statistical tests (Mann-Whitney and Kolmogorov-Smirnoff) have been applied with conflicting results, making it difficult to attach statistical significance to the outcomes. However, the values of speed recorded during incidents in Table 3 do indicate a 2.5 to 4.0 km/h reduction between vehicle speeds in the median and adjacent lanes. This differential appears insensitive to the value of mandatory speed posted during incidents.

Effects of ATMS Architecture on Vehicle Speed

VMSS cannot be considered in isolation when assessing their effects upon vehicle speed. The Variable Message Signs (VMS) clearly play important roles, as do factors such as weather, gradient and varying highway cross section.

Overseas experience suggests that it is the complementary effects of all the various ATMS architecture, which combine to produce the stated benefits claimed from the introduction of ATMS.

Where examples of specific enforcement measures are provided, it is evident that they do result in improved levels of compliance with posted speed limits.

Together, the various pieces of ATMS architecture have produced a safer environment within Ngauranga Gorge SH1 with a reduction in accidents.

However, poor compliance with posted speed limits during incidents raises cause for concern. This is most marked for lower posted speeds set in response to serious incidents, congested conditions, or poor weather conditions. Alternative means of enforcing speeds should be considered.

Analysis of Results

Analysis of the data revealed:

- A high proportion of road users exceed the 80 km/h posted speed limit during normal conditions (40 to 49%), although this percentage is much lower for 100 km/h (3 to 10%).

- Of the incidents examined, 56% were weather related, 25% crashes or breakdowns, and 18% roadworks. Roadworks involved setting the VMSS for the maximum duration (5.5 hours) and, on average, affected 41% of the controlled area.

- Compliance with posted VMSS during incidents was poor. Between 40% and 87% of road users exceeded the specified speed limit, with higher violations occurring at the lower values of speed restrictions (i.e. 50 and 60 km/h).

- At any given location within the affected area, speeds gradually reduce over time during an incident (up to 15 to 20 mins) after which they marginally increase.

- Speeds show a fall over the first 750 m as vehicles pass through the controlled area during an incident.

- Off-ramp volumes increased by up to 40% during incidents, showing the propensity for traffic to divert when road users were advised of incidents downstream of the controlled area.

Conclusions

Road users are largely ignoring the VMSS or failing to reduce the speed of their vehicles to that indicated. This is particularly evident for 'low-speed' incidents (i.e. 50 and 60 km/h) with only a 70 km/h incident posted speed limit showing some degree of adherence and compliance by road users.

In terms of extensions to NATMS or future application within New Zealand, VMSS would appear to offer little additional benefit over Advisory Speed Signs, without effective and active enforcement. However, as they already exist within NATMS, any extension to the Wellington Network may want to consider VMSS for compatibility and familiarity reasons.

Future Research

It would be useful to investigate levels of incidents for motorways carrying different levels of traffic. The assumption is made here that incident management systems such as NATMS would only be introduced on motorways – although they may eventually have a role on high volume urban and rural arterials.

Under the conditions prevailing in the NATMS, it appears pointless to pursue any further additional work on the effects of VMSS.

However, given a controlled environment it would be particularly interesting to investigate:

- the effects of VMSS without the complementary VMS;
- a wider range of speed constraint reflecting varying types of incidents;
- the effect of the active enforcement of VMSS against those systems utilising VMSS **without** visible levels of policing or methods of enforcement;
- further examples of the combined effects of incidents plus inclement weather, to substantiate whether the speed reduction is more marked when both are implemented, against the sole use of speed reductions caused by an incident but **without** the weather factor.

Abstract

The research, carried out during 2002, has examined the effect of Variable Mandatory Speed Signs (VMSS) on road user behaviour within the Ngauranga Active Traffic Management Scheme (NATMS), just north of Wellington, New Zealand. The VMSS show speed limits which are considered appropriate during normal (incident free) conditions and reduced speed limits in response to an incident.

Speed data was acquired through the use of Automatic Incident Detection (AID) cameras using video imaging processing (VIP).

The VMSS are located within the NATMS and are just one component of the dedicated ATMS architecture provided to deal with incidents aimed at reducing delay to road users. The speeds indicated by the VMSS are mandatory and are the only example of such features in New Zealand.

Normal speed data and speeds during incidents were recorded over the period January to August 2002.

1. Introduction

Static speed limit signs governing the legal travelling speed for vehicles using New Zealand roads have been in place since 1898. However, innovation and technological advances in electronics and telecommunications have witnessed the development and introduction of new forms of speed limit signs, which for the purpose of regulatory reasons can be either advisory or mandatory.

The latter method of regulating vehicle speed is the subject of this particular piece of research. The specific intention of the research was to evaluate the effectiveness of Variable Mandatory Speed Signs (VMSS) in controlling vehicle speeds within both normal and incident constrained conditions.

The Ngauranga Active Traffic Management System (NATMS), just north of Wellington, was utilised for this purpose, as it is currently the only location where VMSS have been installed. The ability of VMSS to control vehicle speed is considered fundamental in deciding whether to extend its use to other locations in New Zealand, such as the Auckland ATMS or as possible extensions of the Wellington system.

1.1 Brief Description of NATMS

In February 2001 Transit New Zealand (Transit) commissioned the operation of the NATMS on State Highway 1 (SH1), north of Wellington, New Zealand, which covers a 4 km stretch between Johnsonville and the SH1/SH2 Interchange at Ngauranga.

Figure 1.1 shows the location of the NATMS within the context of the Wellington Region while Figure 1.2 indicates a schematic plan view of the Ngauranga Gorge with adjoining suburbs, important highway structures and intersections, and state highway lane provision in both directions.

The NATMS is a sophisticated electronic system and comprises:

- 23 Variable Mandatory Speed Signs (VMSS) / Lane Control Signs (LCS);
- 6 Variable Message Signs (VMS);
- 12 Automated Incident Detection (AID) Cameras;
- 3 Traffic Flow Monitoring Cameras;
- 7 Pan-Tilt-Zoom (PTZ) Cameras, Closed Circuit Television (CCTV);
- 2 Weather Monitoring Stations;
- Integrated and Control Software at a number of control centres;
- 15 Video Image Processors (VIP).

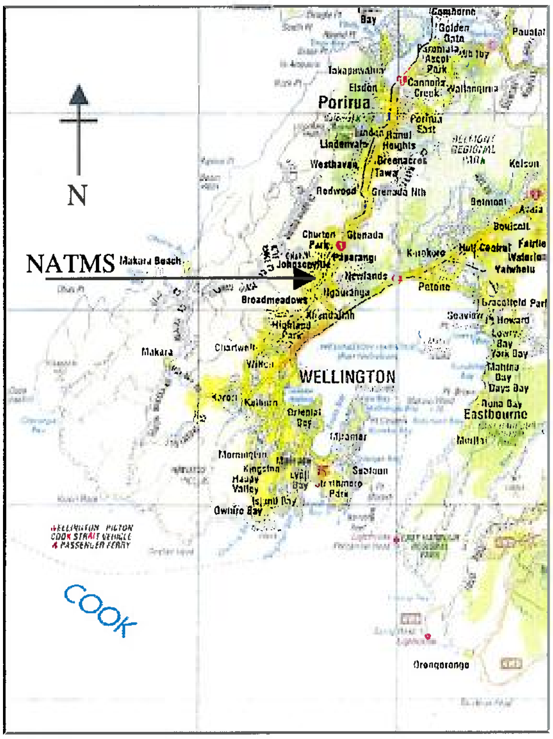


Figure 1.1 Location of NATMS within the Wellington Region.

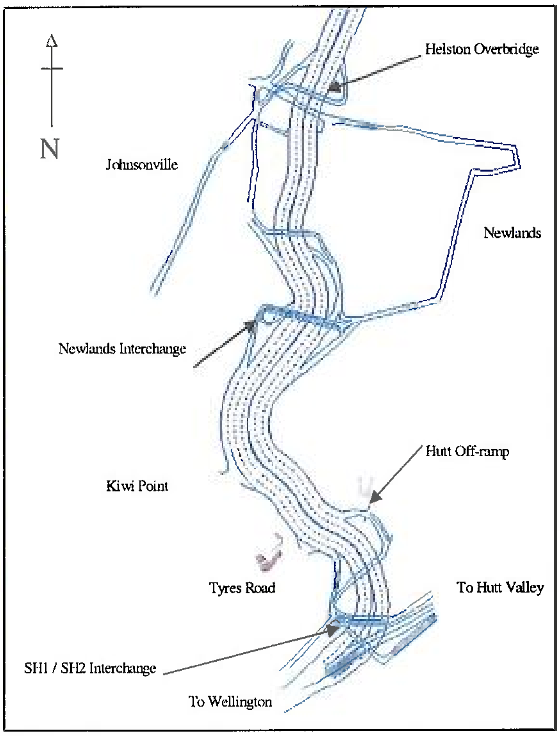


Figure 1.2 Ngauranga Gorge plan view.

1.2 Objectives of the Research

The prime focus of the research was an evaluation of the effectiveness of VMSS to control the speed of vehicles within the NATMS. While this remained the overall principal objective, microscopic analysis and evaluation process were undertaken which sought to establish the following:

(i) **The level of compliance of vehicles with the given speed limit indicated, under both incident-constrained and incident-free conditions.**

The intention of this analysis was to examine if road users behaved differently, particularly during incidents when it could be expected that a lower speed limit would be introduced, together with specific information portrayed on the VMS.

(ii) **The change in vehicle speed and headways through the extent of the NATMS under varying enforced speed limits.**

Under this objective, the intention was to examine the speed of individual vehicles as they travelled through a controlled length of the NATMS, and also to assess if vehicle speed changed as an incident progressed in time.

(iii) Variation in lane-use by vehicle type and time period, under different speed limits.

The original intention here was to verify if vehicles moved from the median (Lane 1) towards the adjacent lane (Lane 2) within the controlled length of highway during an incident, and how this behaviour varied with the time of day and type of incident.

(iv) The extent of traffic which elects to leave the state highway when a speed restriction is in force.

The availability of an off-ramp affording access to Hutt Road (for Wellington CBD southbound traffic) provided the opportunity to assess the amount of traffic choosing to divert, because of measures being enforced arising from an incident. This provided an opportunity to examine the effect of incidents on drivers' route choice.

1.3 Limitations or Amendments to Original Objectives

When the original research proposal was submitted, the precise capabilities of individual features originally intended for the purpose of collecting data were not clear. Subsequent regular use of these ATMS components revealed that they were only suited for incident detection, rather than specifically for data collection purposes. Consequently, the assumptions relating to their employment to define vehicle headway, detailed traffic volume data and vehicle classification proved to be unfounded and some of the original objectives had to be abandoned or revised.

With the inability of the system to measure vehicle headways, much more emphasis was placed on the examination of compliance of road users with posted speed limits. Data on vehicle speed could be recorded within 66 detection zones, providing ample data to look at microscopic effects.

The AID cameras record the speed of individual vehicles at intervals of 0.2 seconds during passage, through the use of Traffic Speed Measurement (TSM) lines, and produce speed characteristics based upon the average value of a given number of recordings within an advancing buffer. This output can be provided at one-minute or five-minute intervals. The former has severe effects on data storage needs and downloading requirements. The latter was considered adequate to reflect changes in speed resulting from incidents, which were of sufficient duration to justify the use of five minutes as a recording interval. The above issues all arose around system or equipment capabilities. However, some specific site characteristics also should be acknowledged and which are clearly reflected in the results quoted. These include:

- A gradient effect – positive in a downhill or southbound direction, with a restraining effect in the northbound direction (amounting to 8% to 10%).

The gradient is considered to have a significant effect on vehicle speed, with heavy vehicles being most affected.

- The cross-section of highway provided in each direction, which can be varied between two and four lanes.

For the purpose of consistency and to enable a meaningful comparison of results to be made, the majority of analyses have been undertaken using data from the median and adjacent lanes.

- The presence of other features of the NATMS which may influence vehicle speed.

This includes the visible presence of a static speed camera mid-way within the controlled section of NATMS and other VMS.

Although it is recognised that VMS may convey information pertaining to an incident and therefore influence road users to travel slower, the VMSS give the speed considered appropriate to the incident and conditions, and are, as such, mandatory. Consequently motorists who exceed the indicated speed are liable to prosecution by the Police. It is this part of the ATMS architecture which is considered more instrumental in governing vehicle speed, although it is acknowledged that the combined effects of the VMSS, VMS, Lane Control Signs (LCS) and the static speed camera are likely to complement each other in reducing speed.

1.4 Research Personnel

The research was commissioned by Transfund New Zealand (Transfund) and undertaken by MWH New Zealand Ltd in Wellington, New Zealand, between August 2001 and February 2003. The research team, peer reviewers and technical advisers are listed in Table 1.1:

Table 1.1 Research Team, Peer Reviewers and Technical Advisors.

Personnel	Position	Organisation
David Turner	Principal Researcher	MWH New Zealand Ltd
Andrew Fergus	Research Assistant	MWH New Zealand Ltd
Roger Dunn	Peer Reviewer	University of Auckland
Dave Rendall	Peer Reviewer	MWH New Zealand Ltd
Rod James	Technical Advisor	Transit New Zealand
Steve Valentine	Technical Advisor	Tyco Integrated Systems
Sean Rainsford	Technical Advisor	MWH New Zealand Ltd
Raj Mellela	Technical Advisor	MWH New Zealand Ltd
John Shrewsbury	Technical Advisor	MWH New Zealand Ltd
Marian Radu	Technical Advisor	Transit New Zealand

The assistance of Bryce McDonald and Gary Hadfield of Tyco Integrated Systems is also acknowledged.

2. Literature Review

2.1 Overview

An initial list was completed of the most recent publications and material on the subject of Variable Mandatory Speed Signs (VMSS). The compilation contained conference papers, journal extracts, periodicals, the internet etc., and was classified in terms of their relevance to Variable Mandatory Speed Signs. Most of the literature is from the United States, Europe and in particular the United Kingdom.

Much of the literature often pertained to methodology for installing VMS and VMSS, such as spacings, sign characteristics, preferable sign symbols and, in one instance, a possible method of analysing results.

The literature review discovered that the control of vehicle speeds has a range of objectives, of which safety is regarded as the highest. Congestion reduction is referred to occasionally. The description of how and where signs should be located is constantly raised in conjunction with what should be displayed on these signs. Driver response in studies was normally questioned, mostly by the means of a postal drop, but in some instances roadside interviews were carried out to ascertain drivers' awareness and recollection of the VMSS signs.

Almost all the literature about systems regarded queue warning as the best use of the VMS hardware. Often the reports would cite reductions in crashes following the implementation of the VMS and VMSS, when typically reductions of 20% to 30% could be expected. However, this avenue of literature search was ignored as it was not one of the objectives of the proposal.

Very few studies outlined in the literature mentioned any consideration of the enforcement of speeds displayed on VMSS. The one clear exception was the system on the M25 motorway in the United Kingdom.

Many of the systems found in the literature review used algorithms and fuzzy logic to identify breakdown in traffic flows. These algorithms were derived from data that was collected from loops in the road and which automatically reduced the speeds indicated on the VMSS.

2.2 VMSS and Enforcement

A section of controlled motorway in the UK, on the M25 orbital motorway just outside London, which began operation in August 1995, is 20 km in length and situated on a dual 4-lane motorway. The concept behind the controlled motorway was that, by controlling the speed of traffic at times of heavy flow, flow breakdown might be delayed or prevented, resulting in a reduction in accidents, an increase in driver comfort and possibly an increase in the throughput over the controlled section (Harbord 1998). This controlled section differed from conventional motorway by the use of 'Variable Mandatory Speed Limits'. Within it is an enforcement system that automatically detects and records vehicles exceeding the speed limit. The system utilises algorithms based on speed data collected from loops in the road to determine when the speeds should be altered.

The above system is designed to enforce all the speed limits that can be displayed on the VMSS and, in the absence of a lower speed limit, the national (70 mph) speed limit. The original algorithm was designed on flow alone and thus could not distinguish between light flow and congestion. As a result the speed limit signals were automatically switched off during serious flow breakdown. It had been expected, based on previous experience from the automatic incident detection trials on the M1 motorway, that drivers would prefer not to see speed limits displayed if they were stationary or in very slow stop-start traffic. This turned out not to be the case, with a clear preference among M25 drivers for the maximum speed limit to be displayed under all traffic conditions.

A study conducted by the Dutch Ministry of Transport on 'Variable Speed Control: State of the Art and Synthesis' (Smulders & Helleman 1998) concluded that enforcement was necessary to achieve a sufficient level of acceptance. However, knowledge of the mandatory speed limit and enforcement are not enough for drivers to adhere to the posted speed. If the control measures are to succeed then an 'inherent acceptability' by drivers of the control is required.

The analysis of traffic speeds on the M25 during the period from May to August 1995, when camera enforcement warning signs were displayed but no enforcement took place, did not indicate any change in the speed of traffic, confirming that fixed signing itself is not a deterrent. Traffic speeds decreased only when the enforcement equipment was brought into use and drivers became aware of the camera flashes.

Drivers' compliance on the M25 confirmed that the system is working. Most drivers were obeying the speed limits and excessive speed has been reduced significantly. Indications were that a small number of drivers increased their speed slightly between signs.

Analysis of the traffic flows confirmed that lane utilisation was also improved. Traffic on the previously under utilised Lane 1 (adjacent to shoulder) increased by 15%. There were indications that lane changing was reduced as drivers were unable to see any benefit in changing lanes when all lanes contained traffic travelling at the same speed.

2.3 Effects of Fibre-Optic Speed Signs on Driver Behaviour

A study in Finland investigated the 'Effects of Variable Speed Limit Signs on Speed Behaviour and Recall of Signs' (Luoma & Rama 1998). The study was undertaken in southern Finland on an inter-urban road, with a fixed speed limit of 80 km/h. A fibre-optic variable speed limit sign (similar to that used in the NATMS) of 60 km/h was installed adjacent to an electromechanical sign and the study involved comparing the speeds of vehicles for each sign, collected from loop data within the road.

Both signs were mandatory. The results found that the fibre optic sign had a lower level of mean compliance speed than the electromechanical sign for both 80 and 60 km/h posted speeds. The average speeds for the fibre-optic sign were 87.7 and 66.3 km/h for the 80 and 60 km/h posted speeds respectively. Also analysis of the number of vehicles exceeding the 60 km/h posted speed was undertaken. The results showed that 82% of traffic in free flow conditions exceeded the speed limit for the fibre-optic sign.

Another study undertaken on the southern coast of Finland involved investigating the 'Distraction Due to Variable Speed Limits' (Rama et al. 1999). The study investigated how the presence of even simple VMS, with important information such as speed limits, may divert the driver's attention from adjacent fixed signing (in this case a general warning sign). The results from the speed analyses were similar to those found in Luoma & Rama 1998, with the mean speed for all vehicles of 85.4 and 68.2 km/h for the 80 and 60 km/h posted speed limit respectively. The conclusion pertaining to the distraction was that drivers were less likely to recall the warning sign when that warning was in the vicinity of the fibre-optic speed limit sign than when the warning was in the vicinity of a fixed speed limit sign. Specifically, 8.3% of drivers who had passed the fixed speed limit sign recalled the warning sign, but only 4.2% of the drivers recalled the warning sign when it was used in the vicinity of the fibre optic variable speed limit sign.

These results support the hypothesis that drivers pay more attention to highly effective signs using fibre-optic technology than to fixed signs and therefore the fibre-optic signs divert the driver attention at the expense of the fixed signs.

2.4 Imposing Speed Constraints

A French study to determine the 'Effects of Variable Speed Limits on Motorways' (Lassauce 1998, cited by Corben et al. 2001) was undertaken on a 12 km section of the A4 motorway in Strasbourg. The arrangement comprised 'advisory speeds' of 50, 70, 90 or 110 km/h being displayed, depending on the traffic density. This study had four aims, among which was to test a new type of variable message annunciate panel. While the variable message panels had the capacity to display emergency messages, only the speed displays were evaluated in this study.

As described by Lassauce, speed limits were displayed on a variable message panel installed in the medium strip at a height of 3.5 metres. Sensors embedded in the road transmitted information regarding the number of vehicles on the road, their average speed over a one minute period, and the gap between vehicles, to the local monitoring stations located at the roadside. The results showed that the traffic flow increased by more than 3,000 vehicles per hour over the life of the trial. There was also a reduction in vehicle speeds between 90 and 110 km/h, an increase in vehicle speeds between 70 and 90 km/h, and a reduction in vehicle speeds below 50 km/h suggesting less variance in vehicle speeds.

2.5 Variable Speed Limits and Safety

In Australia, the Australian House of Representatives Standing Committee on Transport and Regional Services is examining the potential to apply variable speed limits on the F3 Freeway and the Hume Highway between Sydney and Canberra, as case studies of the effectiveness of intelligent transport systems. Among submissions reviewed were examples from overseas including:

- In Germany, a system with variable speed limits is being used on the Autobahn between Salzburg and Munich, between Sieburg and Cologne, and near Karlsruhe, to stabilise traffic flow at times of high congestion, thereby reducing the environmental impacts and the probability of crashes. The data has shown that the use of variable speed limits and warning signs has reduced the crash rate by 20% to 30% (Robinson 2000, cited by DOTARS 2002).

- In the Netherlands near Breda, a variable speed limit system was installed to elicit safer driver behaviour during heavy fog. The posted speed limit is 100 km/h, but this was lowered to 80 km/h and 60 km/h when visibility dropped below 140 m and 70 m respectively. After the system was installed, drivers were found to reduce their mean speeds by 8 to 10 km/h during such conditions (Robinson 2000, cited by DOTARS, 2002).

2.6 Variable Speed Limits and Weather Control

One study in Finland investigated the 'Effects of Weather-Controlled Variable Speed Limits and Warning Signs on Driver Behaviour' (Rama 1999). The study was undertaken on Finland's southern coast on a 14 km interurban highway (E18). Like the M25, the speed limits were lowered automatically, but only during adverse weather conditions, with the speeds limits displayed being mandatory. In this study the speed limit was dropped from 100 km/h to 80 km/h during poor driving conditions in the winter.

The mean effect of lowering the speed limit from 100 to 80 km/h on the test section was a 3.4 km/h drop, in addition to a 6.3 km/h reduction caused by the weather itself. The lowering of the speed limits also decreased the speed variance. Furthermore, the 85th percentile speed decreased more than the mean speed.

Another study conducted in Finland into 'Driver Acceptance of Weather-Controlled Road Signs and Displays' (Rama & Luoma 1997) was designed to investigate the drivers' acceptance of the signs and displays introduced in November 1994 between the cities of Kotka and Hamina on Finland's southern coast, where weather condition changes are particularly frequent. Although this study did not look at speed information, it concluded that drivers on the whole accepted the reason for the reduction in speed, along with the concept that weather control signs and displays were promising.

2.7 Traffic Control using Variable Speed Signs

A Dutch experiment carried out in 1991 studied the 'Control by Variable Speed Signs' (Smulders 1991) and investigated the development of the automatic application of variable speed limits during high traffic demand. The paper outlined the development of new methods to reduce congestion problems experienced on motorways and, in particular, what were the potential benefits of the implementation of VMSS. The conclusion from earlier experiments carried out was that the application of variable speed designs may be of use in situations of high demand and the number of shock waves may be reduced significantly (Smulders 1991). This supports the premise that VMSS are extremely useful in managing congestion.

A number of studies have looked into the effects of variable speeds signs on the speed of vehicles travelling within roadworks. One in particular, undertaken in the North West of England and which focused on safety and capacity, was titled 'Motorway Roadworks: Effects on Traffic Operation' (Yousif 2002). Data was collected in 5-minute intervals and, when analysed, suggested that higher throughput had been obtained when substantial numbers of commuting cars were present. The results found that only 23% and 11% of drivers in Lane 1 (median lane) and Lane 2 (adjacent to median lane), respectively, complied with the speed limit of 50 mph.

A comparison was made between the result from these studies and a previous study (Hunt & Yousif 1993, cited by Yousif 2002) for Lane 1. For Lane 1 it was found that similar compliance was observed for the 50 mph speed limit. Also, the percentages of drivers travelling at speeds less than the speed limit plus 10 mph (i.e. 60 mph) and the speed limit plus 20 mph (i.e. 70 mph) were almost identical in both studies. For Lane 2, there was a lower level of compliance with the 50 mph speed limit compared to Lane 1. However, 96% of vehicles travelled at a speed of less than 70 mph compared to 78% in the previous study. This suggests an overall improvement in the level of drivers' compliance at higher speed limits.

There are many examples of route guidance using VMS throughout the world, particularly in the US and in Europe. One study in Denmark (Dorge et al. 1996), concluded that 25% diversion could be expected by installing a VMS system. However, it should be noted that many of the diversion studies were directly related to route guidance, whereas our research focused on incidents downstream of the NATMS and how drivers use the VMS and VMSS information to influence their choice to either exit the incident-affected section or continue on their existing route.

3. System Definition and Components of NATMS

3.1 System Requirements

The NATMS is the first system in New Zealand to use Automatic Incident Detection (AID) and was chosen because of the challenging driving conditions within the Ngauranga Gorge, which are compounded by steep terrain, numerous bends, and a high degree of weaving between lanes. These, in conjunction with a volume in excess of 60,000 vehicles per day and an accident rate significantly higher than the national average, were contributing factors in the introduction of the NATMS.

The NATMS is designed to reduce the number and severity of crashes, to minimise driver frustration and delay on this demanding section of SH1, and to improve overall traffic flow. This has been achieved by providing up to the minute traffic information to road users, emergency services and traffic controllers via the NATMS. Currently the NATMS is manned 24 hours a day to enable the implementation of faster, more appropriate traffic and emergency responses; these to be provided in accordance with prevailing traffic conditions or incidents, as and when they occur.

Before the introduction of the NATMS, there was no system to enable the Police to accurately determine the nature of an incident within the Ngauranga Gorge. Information was typically received from the public. This process often left room for error regarding the direction and location of the respective incident. Moreover, traffic would often become congested because the incident caused further delay to emergency services in attending the scene. Reaching and isolating the incident quickly, while providing information to drivers approaching an incident, does have a major effect on the level of congestion caused by incidents. This is where the principal benefit of the NATMS lies.

An important feature of NATMS is that it is designed for incident detection. It is not a traffic management tool intended to increase efficiency and reduce travel time.

3.2 Capabilities of the System

Unlike other intelligent transport systems, the NATMS includes a video detection system and incident manager, that automatically alert the operator when an incident has occurred. The detection system raises the incident alarm and automatically links into the appropriate video camera in order to display the relevant video image. Traditionally these systems require human operators to scan banks of video screens to visually detect incidents.

Once incidents are detected by the system, the operator's role is to decide if they warrant the implementation of a predetermined response plan. There are a number of response plans which can be activated within seconds and consist of information placed on the VMS using the operator's own choice from a library of messages. In conjunction with the VMS the operator is more likely to also reduce the speed in the Ngauranga Gorge by lowering the speed limit indicated on the VMSS.

The VMSS on SH1 are displayed in sets; one VMSS being on either side of the carriageway. Typically two sets of VMSS before the incident are activated as a minimum when an incident arises, also further implementation of VMSS may be warranted depending on the type and nature of the incident.

All the architecture is tied together by Odyssey software developed by Philips and divested to Tyco Integrated Systems (Tyco). A graphic user interface (GUI) is used as a platform to manage traffic, provide decision-making facilities, and to control road signs and devices. Information pertaining to incidents is collected using the 12 AID cameras (fixed cameras 1, 2, 3, 4a, 5a, 6, 7a, 7b, 8, 9, 10, 11) and processed using VIPs. This information is then provided to operators containing the incident type, location of where the incident has occurred, by lane and direction. The software is capable of detecting an unlimited number of incidents at any one time.

3.3 Components of the System

There are 23 VMSS / LCS; 11 in the Northbound and 12 in the Southbound direction. The VMSS have the ability to display speeds between blank and 100 km/h in 10 km/h increments. The VMSS signs have a dual purpose, being able to also display lane control instructions. However these are not currently used. Figure 3.1 indicates the location of the VMSS within the Ngauranga Gorge.

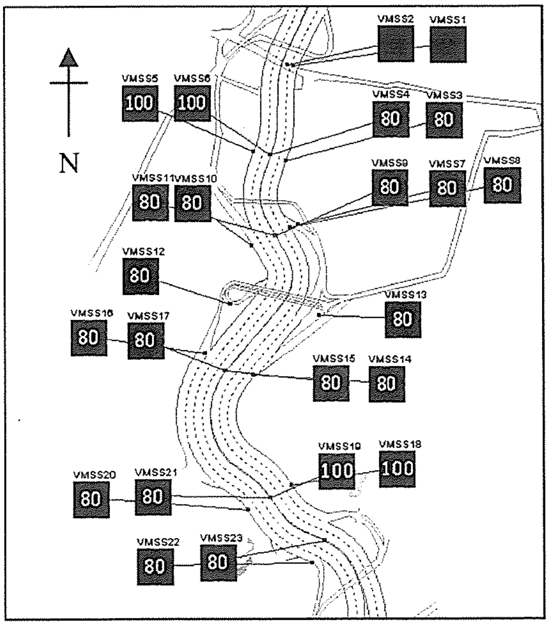


Figure 3.1 Location of VMSS within NATMS.

Six VMS are within the NATMS, four on the State Highway and two on local roads. These signs have been strategically positioned to provide information to drivers, giving them the choice either to continue on their current path or to exit and therefore avoid the incident ahead.

The VMS signs have the capacity to display multi-lined information up to 17 characters long.

The 12 AID cameras are strategically positioned to cover 85% of the carriageway within the Ngauranga Gorge. The data is collected and processed using the AID cameras and independent VIPs, which are the principal methods for detecting incidents and collecting speed data. Only speed and occupancy traffic data are collected on the AIDs and VIPs. These data are collected for all vehicles that are detected but not individual types or classes. It should be noted that the AIDs do not detect a vehicle as such but as a moving item on the screen.

Three data collection cameras (4b, 5b and 12) with VIPs are within the NATMS, dedicated to collecting other traffic information. They provide more information than the AIDs and are intended to collect traffic volume data that can be used to monitor traffic flow.

The three data collection cameras record, among other things, volume, gap time, headway, speed, occupancy, and limited vehicle classification. Again this information is in 5-minute intervals. Figure 3.2 shows the location of all cameras within the Ngauranga Gorge. For this research the three data collection cameras (4b, 5b and 12) have only been utilised for the investigation of the diversionary effect within the NATMS.

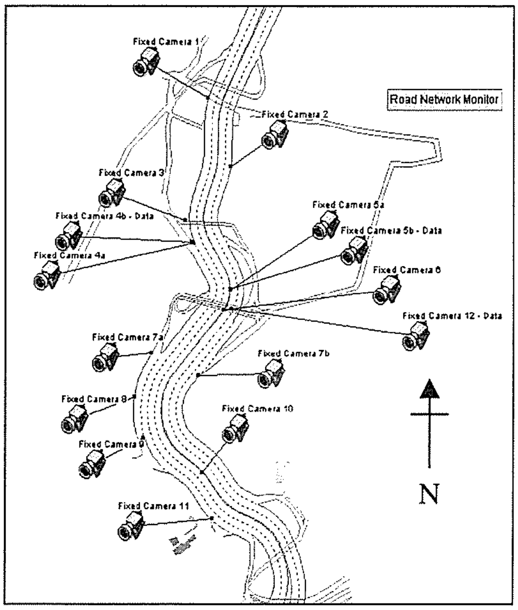


Figure 3.2 Location of cameras within NATMS.

The AID cameras use zonal references to distinguish locations within the Ngauranga Gorge. These zones are a reference for the system and the operators, providing the location for the incidents/traffic information. There are 66 zones within the Ngauranga Gorge, 10 of which are assigned to the data collection cameras, the remaining 56 being assigned to the AIDs.

A zone is typically a short stretch of carriageway capable of detecting vehicular movement, including the highway lanes and the on- and off-ramps. A schematic diagram of zone locations is attached in Appendix A.

There are two weather stations within the NATMS, each with differing modes of operation. One assesses the wetness of the road (%), rainfall (mm), wind speed (m/s), wind direction, and visibility (m). The second weather station records only wind speed and direction.

The seven PTZ cameras are utilised to monitor the Ngauranga Gorge and provide an effective tool for the operators to identify the type and nature of incidents.

The 12 AID cameras cover 56 zones within the Ngauranga Gorge and are the main source of speed data collection. The speed collected is termed 'flow speed', whereby an integration time can be set. For the research the integration time is set at five minutes. This can be lowered to a one-minute interval, but because of the capacity of the current database this was not considered feasible. The integration time is the period over which data are collected by the AIDs and VIPs before reporting to the Wide Area Traffic Telematics Server (WATTS) for processing. The flow speed is not based on individual measurements, but speed is measured along Traffic Speed Measurement (TSM) lines. All data collected is stored in a circular buffer (one that is never empty), and as a vehicle travels along the TSM lines, its speed is recorded every 0.2 seconds.

The buffer stores approximately 50 readings at any one time. There is no set number of measurements per vehicle, but the idea behind the flow speed concept is that the slower a vehicle is travelling the more impact this vehicle has on the flow speed calculation. This allows the system to detect slow moving vehicles and/or stopped vehicles, enabling it to trigger the Incident Manager much faster than if the average speed of vehicles was used. If average speed was used it may take 20 vehicles moving at slow speed to bring the flow speed down to the real situation, whereas with the flow speed concept the speed will reduce more quickly. This is the major principle behind using the system for incident detection rather than as a data collection tool.

While the flow speed amasses, data in a buffer is being constantly updated as vehicles move along the TSM lines. As new measurements enter the circular buffer the oldest ones are discarded. When no vehicles are moving along the TSM lines, no measurements are taken and, therefore the flow speed remains unchanged. When it comes to reporting flow speed to the WATTS, the actual flow speed at that instant (i.e. every 5 minutes) is exported.

The WATTS is currently housed in the Johnsonville Police Station along with a control station. The System can now be operated by computer control stations at the following locations:

- Johnsonville Community Policing Centre (JCPC)
- Wellington City Council Traffic Control Centre
- Auckland Transit Traffic Operation Monitoring System (ATTOMS)

Information stations are also situated at the Central Communications Centre of the Wellington Central Police Station and at Transit Wellington Regional Office.

4. Data Collection Process and Methodology

4.1 Derivation of Base Profiles

4.1.1 Ngauranga Gorge

The NATMS architecture was used to obtain data pertaining to speeds that reflected normal flow conditions. Normal speed flow conditions were defined as 'any time where the VMSS displayed their default speeds and no incidents were present'. The default speeds are shown in Figure 3.1 with VMSS 1 and 2 being blank, VMSS 5, 6, 18 and 19 displaying 100 km/h, and the remaining 17 VMSS displaying 80 km/h.

Data were collected from late January to May 2002 from all AIDs and VIPs, with summarised printouts at 5-minute intervals. In producing the base profiles, data records were inspected visually to identify 'untypical' days or periods of time when the data appeared to be 'dubious'. Such 'abnormal' periods were removed from the database. They included data acquired during roadworks, crashes and inclement weather incidents within the Ngauranga Gorge, in addition to public and school holidays when abnormally light flows were experienced. A sample of normal flow condition days was extracted from the WATTS database to determine an overall base profile for normal speed flow conditions. Furthermore, specific zones were removed from the normal flow day, due to irregular speeds or the need for calibration.

Speed data was grouped covering four periods of the week and further broken down into specific times of the day, as follows:

Monday – Thursday:	Morning Peak 07:00 – 10:00
	Inter-peak 10:00 – 16:00
	Afternoon Peak 16:00 – 19:00
	Night Time 19:00 – 24:00 and 00:00 – 07:00

Friday:	Morning Peak 07:00 – 10:00
	Inter-peak 10:00 – 16:00
	Afternoon Peak 16:00 – 19:00
	Night Time 19:00 – 24:00 and 00:00 – 07:00

Saturday:	One base profile covering the whole day

Sunday:	One base profile covering the whole day

The above groupings and times were selected after detailed analysis of traffic volume data acquired from Transit (Wellington Region) and Wellington City Council. Both sources revealed quite different profiles between individual days, with weekends (Saturday and Sunday) lacking defining morning or afternoon peaks, but nevertheless having high volumes related to the attractiveness and availability of retail and recreational facilities within the CBD and immediate surrounding areas.

A separate analysis was undertaken within the morning peak in the southbound direction for a posted speed of 60 km/h. Currently a procedure is in place whereby speeds in the southbound direction are reduced to protect the back of the morning queue. This queue is a result of the breakdown in flow at the SH1/SH2 merge, the queue typically extending back up Ngauranga Gorge and in some instances beyond the northern extremity of the Gorge. The 60 km/h speed limit was considered 'typical' as this occurs on all weekday mornings. However the extent of the queue and the time of its occurrence requiring the introduction of 60 km/h posted speed signs do vary from day to day.

The days chosen in 2002 for base profile analysis were:

- Monday–Thursday: 28 January, 30 January, 26 February, 27 February, 25 March, 28 March, 16 April, 24 April, 30 April, 1 May, 2 May, 7 May, 9 May.
- Friday: 22 February, 19 April, 3 May, 10 May.
- Saturday: 2 February, 9 February, 2 March, 9 March, 27 April, 4 May, 11 May.
- Sunday: 3 February, 10 February, 24 February, 3 March, 5 May, 12 May.

The overall intention of this part of the research was to produce speed profiles to represent the average speed of a vehicle within any zone of the NATMS by time of day.

4.1.2 Hutt Off-Ramp

A base profile for vehicles using the Hutt Off-ramp was also compiled using the same principles covering the other speed flow profiles. This is a volumetric data profile and distinctly different from the others, which are all speed related. The Hutt Off-ramp can be used by road users if desiring to access the Wellington CBD by the Hutt Road. Specific incidents on SH1, south of the Ngauranga Gorge, can produce the incentive for road users to divert. The development of this profile utilised data obtained from two cameras (5b and 12) and traffic volume data from Transit's telemetry site south of the Ngauranga Gorge. A loop counter was placed at the Hutt Off-ramp to determine if the data collected from the VIP cameras and Transit's Ngauranga Gorge telemetry site could be used together to provide a base profile.

Output from both sources is shown in Appendix B and exhibits a reasonable level of agreement.

4.2 Acquisition of Incident Data

Incident monitoring was conducted from the end of January 2002 until late August 2002. An incident is defined as 'any occasion when the speed indicated by a VMSS was reduced for longer than one minute from its normal posted speed'. Often instances occur within the confines of the Ngauranga Gorge that do not warrant a reduction in speed. An example of these would be a breakdown with a vehicle located in the shoulder, well clear of the operational traffic lanes.

4.2.1 Aggregate Evaluation

The analysis of incidents includes a summary of all incidents that occurred within the Ngauranga Gorge from 28 January to 31 August 2002 (7 months). Incidents were classified by type of incident occurring and categorised using the four following groupings:

- Unplanned
- Roadworks
- Wet Weather
- Other/Unsure

Other/unsure included incidents that were infrequent in nature, such as diesel spills and rockslides, and also incidents whose causes were uncertain.

Incidents were further analysed to determine the average duration and the average area affected. For the former, the start and end time for each incident had to be determined. The start time was defined as when the speed on the VMSS was first reduced and the end was defined as the time when the last VMSS was returned to the speed it indicated prior to the incident occurring.

The area affected was investigated to determine the percentage of the controlled area affected by an incident. This area was defined as the distance between the first VMSS which displayed a reduced speed, and the first VMSS passed by drivers which displayed its default value. This distance was expressed as a percentage of the total length of the NATMS that contained the VMSS signs, being 2970 m in each direction. In the northern direction the final set of VMSS were assumed to cover a distance of 455 m, i.e. the distance from that set to a local road overbridge. This distance was assumed to be appropriate as it coincided with the northern boundary of the final VMSS. The final pair of southbound VMSS defined the southern extremity of the zone of influence and was assumed to cover a distance of 415 m, i.e. the distance from the final pair of VMSS to a rail overbridge.

A summary of incidents was also undertaken to determine any evidence of monthly or seasonal variability.

4.2.2 Microscopic Study of Incidents

A microscopic investigation of incidents was undertaken to examine driver behaviour when subjected to a reduction in speed through the introduction of VMSS in response to various incidents. For the purpose of this part of the study, data was only acquired during the first hour following the introduction of an incident management plan.

Two individual characteristics were studied in some detail. These included:

- Time Effect – how vehicle speeds change over time in a particular zone during the course of an incident. This was achieved by comparing the speed recorded at each 5-minute interval during an incident, with that recorded during the previous 5-minute period.
- Distance Effect – this involved analysing how vehicle speeds changed as they progressed through the area controlled under an incident management plan. The analysis compared the speed in the first zone under restriction with that of all the following affected zones, for the same 5-minute period.

4.3 Determining the Diversionary Effect

Notification of incidents which occurred south of the NATMS on SH1 provided drivers with the opportunity to divert and leave SH1 (or SH2), using the Hutt Road for their journey into Wellington.

The assessment of the diversionary effect necessitated an approach which relied upon comparing the volume exiting at the Hutt Road Off-ramp on 'normal' days, with that during times when the VMS displayed messages pertaining to incidents south of the NATMS.

A temporary counter was placed across the off-ramp to determine traffic volume profiles during an incident free week for Monday–Thursday, Friday, Saturday and Sunday during 15-minute periods.

While the method provided profiles over a complete week, it could not be used for comparison purposes at times when an incident occurred. Consequently, it was hoped that traffic data acquired by the cameras at Johnsonville, together with that from the Transit telemetry site at the southern end of NATMS, could be calibrated against the temporary loop count and subsequently provide traffic volume data during times of incidents.

The calibration results are given in Table 4.1. The difference between the two sources can be regarded as minimal and suggests that the cameras and telemetry site can be used as an indicator to determine if there is a diversion of traffic during an incident.

Table 4.1 Hutt Road calibration test.

Day	Loop Counter at Hutt Off-ramp	Hutt Off-ramp count derived from Data Cameras and TMS	Difference	Percentage Difference
Saturday 27 July 2002	10540	10058	-482	4.6%
Sunday 28 July 2002	8076	8182	106	1.3%
Monday 29 July – Thursday 1 August 2002	13044	12170	-874	6.7%
Friday 2 August 2002	13603	13047	-556	4.1%

Once satisfied as to the robustness of the methodology, traffic volumes were measured during periods affected by incidents and when diversion could therefore be an option. Once again public and school holidays were disregarded. Also problems with the telemetry site further reduced the number of incidents available for investigation.

4.4 Data Collection and Constraints

The following sections describe some of the constraints and limitations encountered during the course of planning and executing the data collection programme. Wherever possible, solutions are provided to support the desired research project outcomes.

4.4.1 Issues pertaining to Quantifying the Start of an Incident

As the system collects data at 5-minute intervals, it was considered appropriate to disregard incidents which lasted less than 3 minutes, as this period was considered too short to affect the speeds collected by the AIDs. Furthermore, incidents that began during a 5-minute recording interval and only lasted for 4 minutes were also disregarded, as the 1-minute period between the removal of the VMSS and the next speed export to the WATTS database was considered to have a significant effect on the speeds collected.

For incidents that commenced on or within 1, 2 or 3 minutes before a 5-minute recording period, that 5-minute period was considered to be the first 5-minute period of an incident. A period of 4 minutes before a WATTS export was considered long enough to have a reasonable effect on the speed.

The table below is an example of how the actual start of an incident and that assumed for the purpose of analysis are rationalised.

Table 4.2 Analysis start times.

Time when VMSS was Reduced	Beginning of Analysis
20:30	20:35
17:21	17:25
10:52	11:00
01:44	01:50

4.4.2 Comparison of Incidents with Base Profiles

Only incidents during which all lanes remained open were analysed. This was undertaken to ensure that similar flow characteristics could be experienced between the base conditions and the incident conditions. Incidents that had lane closures in place were excluded from the behavioural part of the study, but are reflected in the aggregate analysis of incidents.

4.4.3 Maintenance and System Calibration

Although the system has been operating since February 2001, upgrades, maintenance, and calibration still need attending to periodically, and faults still occur. A number of these occurred within the data collection period. On 8 August 2002, the system was upgraded to cover the Terrace Tunnel Upgrade on SH1 within Wellington. This was introduced into the NATMS main processing equipment and caused a change in the integration time. This upgrade lowered the integration time from 5 minutes to 1 minute. This effectively brought to an end the 5-minute periods for quantification of incidents.

Data was also lost when maintenance occurred, and often the system was unavailable for 4 or 5 hours at a time. When this occurred, data collection capabilities were lost and hence no microanalysis of incidents could occur during these periods. However aggregate analysis could still continue, as the information pertaining to the times when the VMSS signs were implemented still remained.

Calibration of the system was undertaken once within the data collection period. This was because one AID camera, Camera 10, was not properly calibrated. The data outputs from Camera 10 were extremely high, speeds in the order of 100 to 120 km/h were being registered, whereas the surrounding AID cameras were recording speeds in the order of 80 to 100 km/h. Consequently all data collected by AID Camera 10 were removed from the microscopic analysis before calibration was completed.

4.4.4 Redefinition of Incidents

With the advent of full time monitoring of the NATMS for 06.30-19.00 from April 2002, the opportunity was taken to redefine unplanned incidents to allow for a more detailed description. A sub-classification system involving breaking down unplanned incidents into breakdowns, crashes and spills, was adopted. Prior to April 2002, unplanned incidents could only be categorised as a single category.

4.4.5 Untypical Days

The collection of incident data was undertaken between 28 January 2002 and 31 August 2002. Although this suggests that 216 days of information were available, not all of these could be used for incident analysis, for example, school and public holidays. These days were removed from the microanalysis as the traffic patterns were considered to be different from normal school days.

A complete list of days not included in the microscopic analysis is shown below in Table 4.3.

Table 4.3 Data omitted from incident analysis.

Date	Reason for Exclusion	Total number of days lost
6/02/02	Public Holiday – Waitangi Day	1
12/03/02 – 22/03/02	No Speed data available from WATTS	11
29/03/02 – 14/04/02	School Holidays (Easter included)	17
25/04/02	Public Holiday – Anzac Day	1
3/06/02	Public Holiday – Queens Birthday	1
29/06/02 – 14/07/02	School Holidays	16
8/08/02 – 31/08/02	Integration time changed to from 5 minute to 1 minute	24
	Total Days Lost	**71**

4.4.6 Specific Site Problems

The possible influence of VMS, a fixed speed camera, and significant gradients are recognised and it is acknowledged that it is virtually impossible to isolate the effect of VMSS on vehicle speeds independently.

5. Evaluation of Normal and Incident Conditions

5.1 Approach of Evaluating Data

As previously explained in Section 4.1, the data collection encompassed the acquisition of data using four discrete periods during a week, each of these being further divided into time periods within a day.

In analysing 'incident free' or 'base-profile' conditions, the above classification system has been adopted, together with further categorisation according to prevailing speed limit. This can be 100 km/h, 80 km/h or 60 km/h – the last of these reflecting congestion during the morning peak (southbound direction) and therefore considered as typical because it occurs regularly during weekdays.

In quantifying and evaluating incidents, category headings using 'unplanned', 'wet-weather', 'roadworks', and 'unknown' have been adopted. The analysis has also considered the number and proportion by type, the duration of each incident and proportion of highway affected.

Speed profiles during incidents, which show non-compliance with the posted speed limit, have been developed for the different incident type categories covering 50 km/h, 60 km/h, 70 km/h and 80 km/h. It should be appreciated that some categories of incident have very low levels of occurrence and the results from these should be viewed with caution.

In addition, the acquisition of considerable amounts of data has enabled the following behavioural characteristics to be examined:

(i) The breakdown of normal flow condition during the a.m. peak and the development of a shock-wave from the initial point of congestion (the SH1/SH2 merge) back up the Gorge;

(ii) the change in speeds recorded in any one zone during an incident, and how this varies as an incident proceeds;

(iii) how speed varies from zone to zone at any instant in time;

(iv) the proportion of traffic opting to leave SH1 and use Hutt Road as an alternative route, because an incident had occurred downstream of the controlled area.

5.2 Compliance with Posted Speeds during Normal Flow Conditions

Detailed vehicle speeds recorded in accordance with the criteria specified below are given in Appendix C.

In addition to the time of day, the day of the week and speed limit in force, actual recorded speeds are given for each lane. However, with different cross-sections being reflected within the controlled section, comments have centred upon results pertaining to the two lanes in each direction adjacent to the median strip and crash barriers, which are common throughout the controlled area.

For comparison purposes, recorded speeds have been summarised by their mean, standard deviation, 85th percentile speeds and percentage exceeding the posted speed limit.

While detailed data are available covering the effects of posted speed limits by lane use, time and direction, the severe uphill gradient confronting vehicles travelling north clearly contributes towards lower speeds and the ability of vehicles to travel at the posted speed limit. The reverse is true in the southbound direction where the gradient increases vehicle momentum, because of natural gravitational effects. Although some discussion does focus on vehicle speed by different direction, most of the analysis has been conducted on data acquired in the southbound direction.

5.2.1 Speed Characteristics by Direction

Table 5.1 indicates values of various speed characteristics by direction, with the median and adjacent lanes being evaluated together.

Table 5.1 Base profile speeds (southbound).

Days	Mon-Thurs		Friday		Saturday		Sunday	
Speeds (km/h)	80	100	80	100	80	100	80	100
Mean	77.9	86.4	78.8	87.0	81.6	86.5	81.5	87.8
Standard deviation	10.1	10.9	11.5	10.2	15.1	9.6	13.3	9.5
85th percentile speed	89.0	98.0	90.0	98.0	95.0	97.0	94.0	99.0
% exceeding posted speed limit	33.0	9.0	36.0	10.0	43.0	10.0	39.0	11.0

Table 5.2 Base profile speeds (northbound).

Days	Mon-Thurs		Friday		Saturday		Sunday	
Speeds (km/h)	80	100	80	100	80	100	80	100
Mean	78.1	85.1	77.7	85.3	80.5	85.6	81.1	87.1
Standard deviation	11.6	7.7	11.5	6.8	10.5	8.0	10.3	6.6
85th percentile speed	90.0	93.0	89.0	92.0	91.0	94.0	91.0	94.0
% exceeding posted speed limit	43.0	1.0	42.0	1.0	53.0	3.0	56.0	2.0

General comments pertaining to the results given in the tables above include:

- Southbound speeds are marginally higher than northbound speeds. For 80 km/h, the difference is between 0.4 and 1.1 km/h, increasing to between 0.7 and 1.7 km/h for a 100 km/h posted speed limit. This reflects, as discussed earlier, the effects of the gradient.
- Days when lighter flows can be expected (i.e. Saturday and Sunday) experience higher speeds than weekdays. For 80 km/h, the difference is 2.4 to 3.0 km/h, reducing to 0.1 to 1.8 km/h for a 100 km/h speed limit.

- The standard deviation of speeds usually exhibits greater variability in values recorded under an 80 km/h speed limit as against a 100 km/h speed limit.
- For vehicles travelling through the controlled zone subject to an 80 km/h speed limit, non-compliance at all times is very high, with percentage of vehicles exceeding the posted speed limit being between 33% and 56%. Non-compliance within zones subject to a 100 km/h speed limit is however lower, ranging from 1.0% to 11.0%. (Non-compliance under an 80 km/h regime is highest in the northbound direction, while the reverse is true for a 100 km/h speed restriction.) Southbound vehicles exhibit greater likelihood to exceed the posted speed limit.
- Generally, the 85th percentile speed is approximately equal to the mean plus one standard deviation. This infers that vehicle speeds are less spread (i.e. have less variance) than if they conformed to a normal distribution.

5.2.2 Speed Variability by Time of Day

Figures 5.1 to 5.6 enable some comparison to be made of variation in speed characteristics, by time of day, for both Monday to Thursday and Friday, in the median and adjacent lanes (Lanes 1 and 2 respectively).

Only the southbound data have been used for assessment purposes, although similar values could be expected in the northbound direction, except that the morning peak would be reflected as an evening peak.

5.2.2.1 *Average Speed and 85th Percentile Speed*

Average speeds and 85th percentile speeds are shown in Figures 5.1 and 5.2. The lowest speeds occur during the period 07.00 to 10.00, which encompasses the morning peak. The speeds during this time are some 5 to 10 km/h below comparable speed during other periods.

In the median lane (Lane 1), average speed tends to be greater than that in Lane 2 by between 3.7 and 5.9 km/h (for 80 km/h speed limit) and between 3.5 and 7.7 km/h (for 100 km/h speed limit).

5.2.2.2 *Standard Deviation*

Standard deviations are shown in Figures 5.3 and 5.4 and exhibit maximum variation during the period 07.00 to 10.00, reflecting the morning commuter peak and the likelihood of varying levels of traffic congestion.

It is not possible to make conclusive statements regarding the values of standard deviation by lane at other times, because of conflicting results.

5.2.2.3 *Compliance with Speed Limits*

Figures 5.5 and 5.6 show the highest level of non-compliance during the time period 10.00-16.00.

As expected, the percentage exceeding the 80 km/h speed limit is highest in Lane 1 (29% to 56%) against 14% to 31% in Lane 2. Comparable figures for a 100 km/h speed limit are 5% to 29% for Lane 1 and 0% to 11% for Lane 2.

Of the two timeframes compared, the level of non-compliance appears to be higher for a Friday than for Monday to Thursday, perhaps reflecting a slightly reduced volume of traffic flow on Friday offering drivers more freedom to select their desired travel speed.

5.3 Incident Characteristics

5.3.1 Incident Occurrence

Incident data was acquired over the period January to August 2002. During this period, a total of 247 incidents occurred, with the breakdown being as given in Table 5.3. Weather-related incidents (56%) dominate the statistics which cover wet road surface conditions or times when heavy rain occurred.

Table 5.3 Classification of incidents.

	Type of Incident				
	Roadworks	**Weather**	**Unplanned**	**Other/Unsure**	**Total**
No	44	138	62	3	**247**
%	17.8%	55.9%	25.1%	1.2%	**100%**

The most interesting category of incident is probably that termed 'unplanned' – as it results naturally, not being preconceived or prearranged.

From April to August 2002, unplanned incidents were classified in accordance with the categories given in Table 5.4. Note that crashes and breakdowns virtually constitute the total and have a similar level of occurrence.

Table 5.4 Analysis of unplanned incidents.

Type of Incident	Number	Percentage (%)
Crash	24	51.1
Breakdown	19	40.4
Spillage	1	2.1
Other*	3	6.4
Total	**47**	**100**

*Includes 2 slips and 1 unknown

In terms of timing, the highest number of incidents occurred during June (1.27/day) and July (2.00/day). This would suggest some connection between inclement weather and the frequency of incidents.

Figure 5.1 Average speed and 85th percentile by time of day for 80 km/h posted speed (southbound).

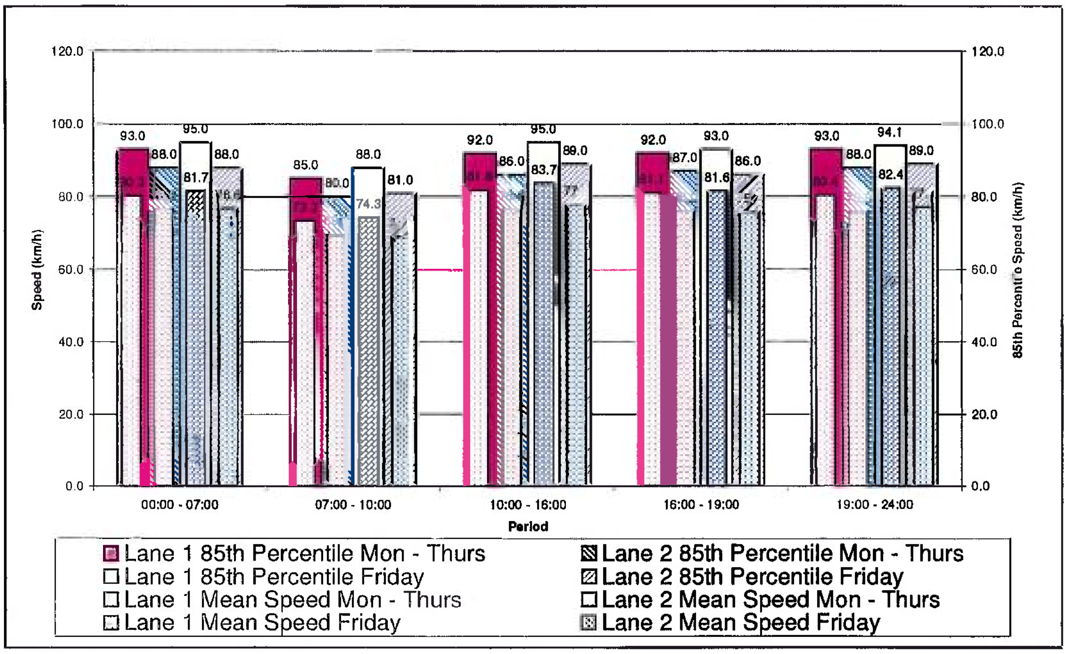


Figure 5.2 Average speed and 85th percentile by time of day for 100 km/h posted speed (southbound).

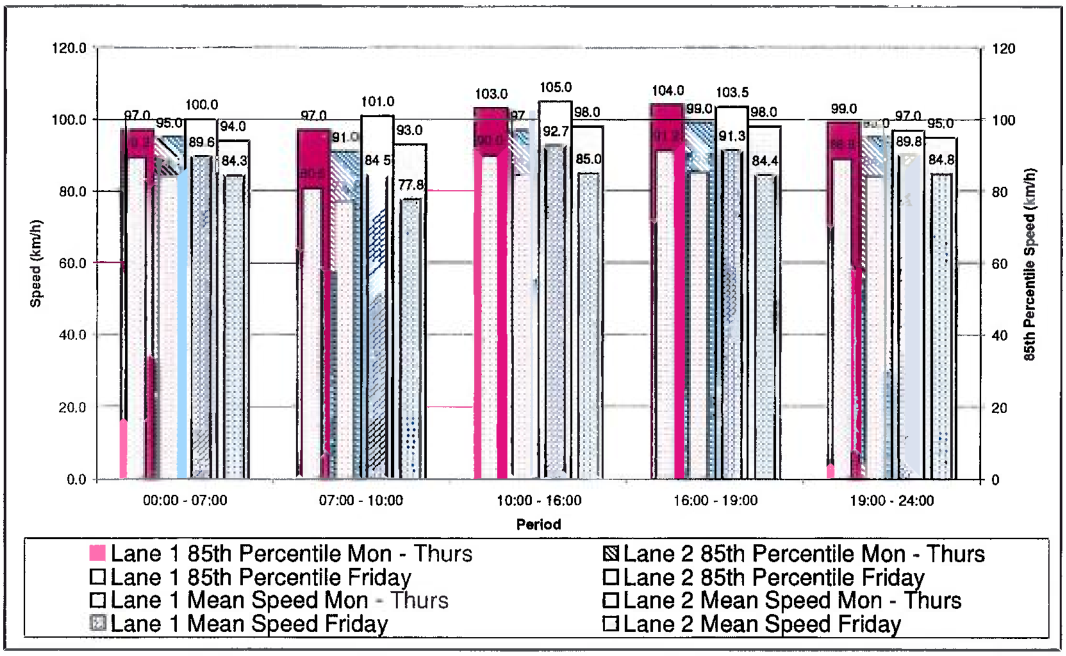


Figure 5.3 Standard deviation by time of day for 80 km/h posted speed limit (southbound).

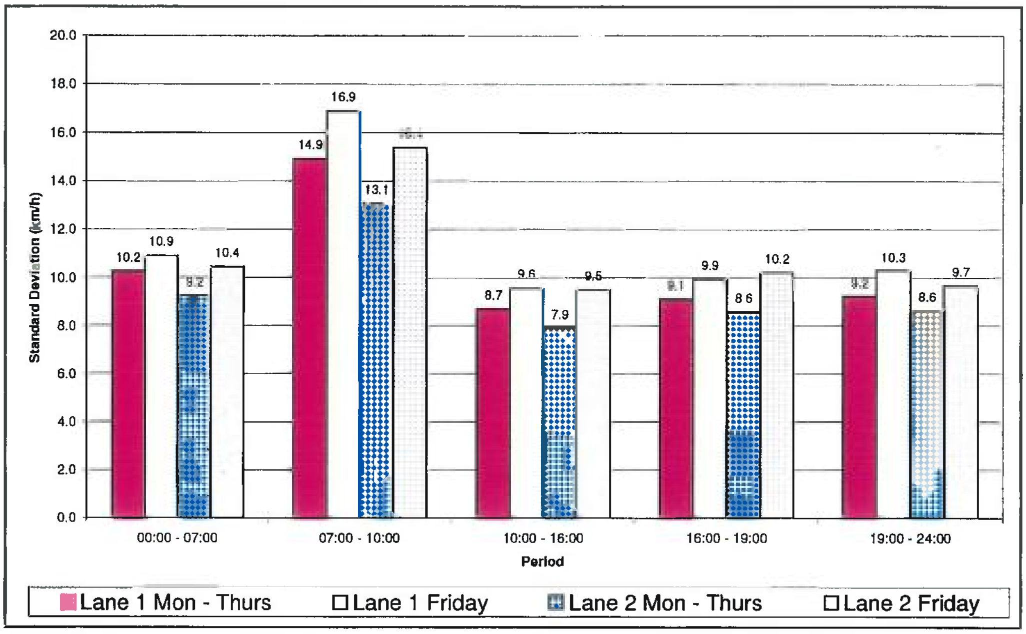


Figure 5.4 Standard deviation by time of day for 100 km/h posted speed limit (southbound).

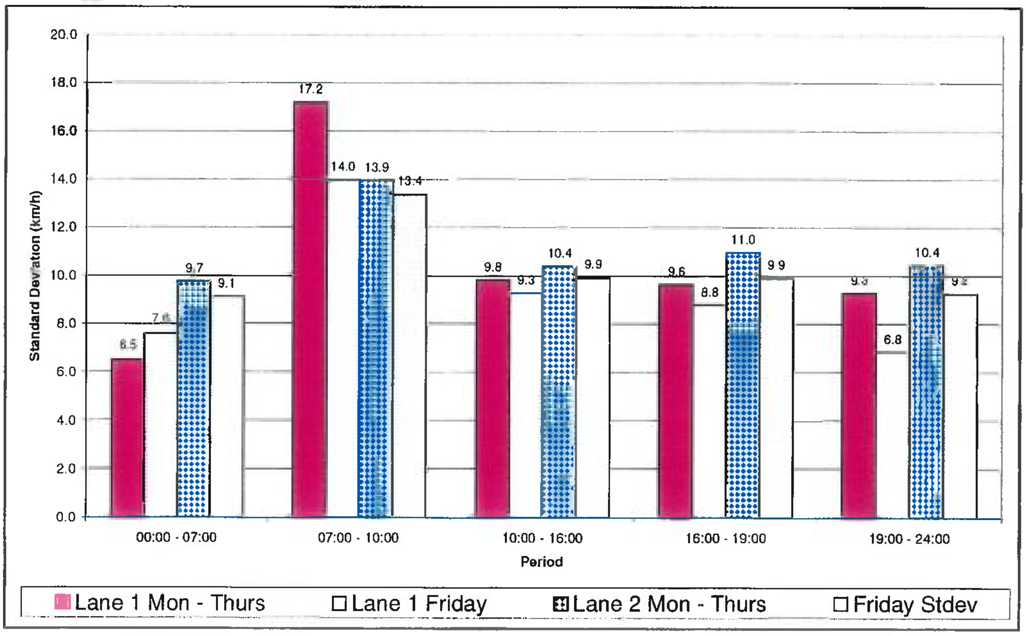


Figure 5.5 Percentage exceeding posted speed limit of 80 km/h (southbound).

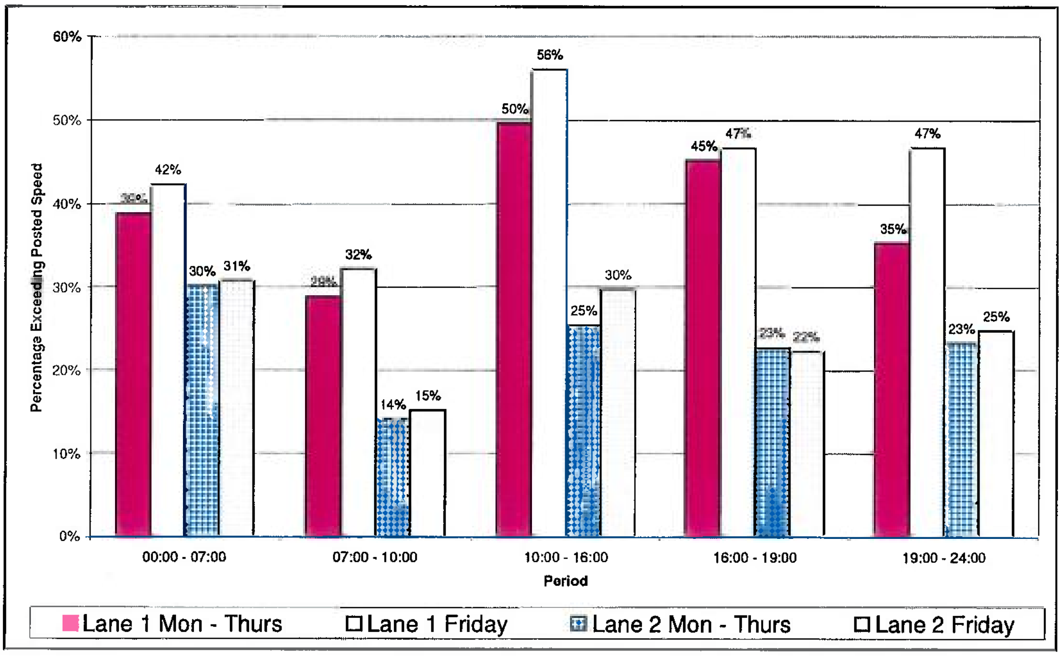


Figure 5.6 Percentage exceeding posted speed limit of 100 km/h (southbound).

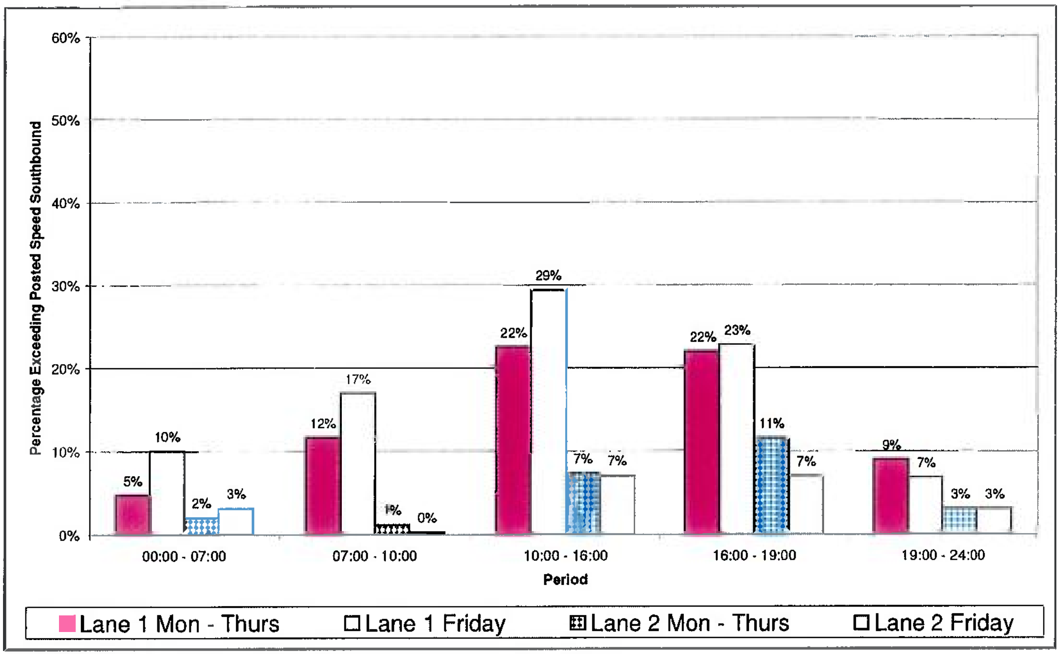


Table 5.5 Relative frequency of incidents.

Period		Incident	
Month	**Days**	**Total**	**Number/Day**
January	4	2	0.50
February	28	30	1.07
March	31	33	1.06
April	30	29	0.97
May	31	22	0.71
June	30	38	1.27
July	31	62	2.00
August	31	31	1.00

An assessment of the directional distribution of incidents proved inconclusive. For unplanned, a 50:50 distribution would be logically expected. However, Table 5.6 suggests that northbound incidents are dominant.

Table 5.6 Directional distribution of incidents.

Incident	Total Number	Direction	
		North (%)	**South (%)**
Roadworks	44	59	41
Weather	138	0	100
Unplanned	62	60	40
Other/Unsure	3	33	67

The 100% of incidents in the southbound direction pertaining to weather are a peculiarity associated with NATMS operational procedures. The only weather-related VMSS reduction affects the 100 km/h sign before the SH1/SH2 merge, which is reduced to 80 km/h during times of inclement weather.

In terms of the duration of different types of incident and extent of the controlled area affected, Table 5.7 suggests that reduced speed limits shown by VMSS lasted for much longer periods for roadworks and weather-related incidents, than for the other categories of incidents. Unplanned incidents (crashes and breakdowns) were dealt with in a relatively short period, but did affect a significant proportion of the controlled zone.

Table 5.7 Length of incidents and area affected.

Incident	Average Duration (h:min)	Average Area Affected (%)
Roadworks	05:22	41
Weather	04:22	14
Unplanned	00:35	47
Other/Unsure	00:17	33

5.3.2 Speed Reductions caused by Incidents

Table 5.8 presents the results from an analysis of incidents by type, direction, lane, and for different posted speed limits.

The values in brackets represent the number of 5-minute speed recordings. Some of the values suggest that very few incidents are reflected in the values of the average speed given for different types of incident and hence should be viewed with caution.

Overall, most road users obviously find it difficult to comply with the posted speed limit of 50 km/h and in general this trend is more marked at lower speeds.

Table 5.8 Mean recorded speeds by type of incident.

Incident Type			Posted Speed (km/h)			
			50	60	70	80
Roadworks	Northbound	Lane 1	63.0 (104)	N/A	73.4 (228)	N/A
		Lane 2	57.9 (91)	N/A	70.5 (228)	N/A
	Southbound	Lane 1	67.3 (59)	N/A	67.0 (312)	82.4 (30)
		Lane 2	64.7 (59)	N/A	58.7 (299)	82.9 (36)
Unplanned Pre-April	Northbound	Lane 1	67.6 (85)	40.8 (67)	N/A	N/A
		Lane 2	63.6 (85)	41.3 (67)	N/A	N/A
	Southbound	Lane 1	N/A	70.7 (101)	N/A	90.9 (37)
		Lane 2	N/A	64.7 (101)	N/A	87.4 (47)
Crash	Northbound	Lane 1	N/A	73.5 (158)	N/A	N/A
		Lane 2	N/A	67.0 (157)	N/A	N/A
	Southbound	Lane 1	N/A	47.3 (100)	N/A	95.2 (10)
		Lane 2	N/A	51.5 (87)	N/A	90.9 (10)
Breakdown	Northbound	Lane 1	N/A	72.3 (160)	94.0 (1)	N/A
		Lane 2	N/A	68.8 (159)	91.0 (1)	N/A
	Southbound	Lane 1	N/A	72.3 (56)	N/A	N/A
		Lane 2	N/A	69.5 (62)	N/A	N/A
Other	Northbound	Lane 1	N/A	63.3 (60)	N/A	N/A
		Lane 2	N/A	60.6 (60)	N/A	N/A
	Southbound	Lane 1	N/A	78.1 (14)	N/A	N/A
		Lane 2	N/A	73.4 (13)	N/A	N/A
Wet Weather	Southbound	Lane 1	N/A	N/A	N/A	90.4 (856)
		Lane 2	N/A	N/A	N/A	88.2 (856)
All	**Northbound**	**Lane 1**	**63.6 (189)**	**66.8 (445)**	**73.5 (229)**	**N/A**
		Lane 2	**60.6 (176)**	**62.9 (443)**	**70.6 (229)**	**N/A**
	Southbound	**Lane 1**	**67.3 (59)**	**62.8 (271)**	**67.0 (313)**	**90.2 (933)**
		Lane 2	**64.7 (59)**	**61.9 (263)**	**58.7 (299)**	**87.9 (949)**

( ) indicates sample size. Lane 1 represents the median lane, with Lane 2 being the adjacent lane.

5.4 Behavioural Features Associated with VMSS

5.4.1 Morning Peak Time

The key limiting constraint on the capacity of the Wellington Urban Motorway (the SH1/SH2 merge) lies within the study area (refer to Appendix A). Here two lanes from each of SH1 and SH2 (southbound) meet at a merge (unprioritised) with a resulting lane drop to three lanes.

The merge regularly breaks down under the effects of peak hour morning traffic demand, with the resulting queue quickly extending back up the Gorge, although the timing and the length of the queue can vary.

Speed profiles are presented in Figures 5.7 and 5.8 respectively for Zone 44 (southern end of Gorge). and for Zone 25 (at Johnsonville). The distinguishing features of the profiles include:

- A regular and very pronounced flow breakdown at the southern end with a recovery, which varies in time, and followed by a return to a speed similar to that before the flow breakdown.

- Individual traces suggest that speed can fall to as low as 15 km/h, with flow breakdown sometimes extending for up to one hour. This is related to the changing cross-section of the highway, which changes from two to three lanes and back to two lanes through the controlled area.

- Typically, queues develop both at the merge and northern extremity of the Gorge, where SH1 is restricted to two lanes. Mid-section, the three lanes provide sufficient capacity to prevent congestion occurring.

- Breakdown at the northern end does not occur on a regular basis. The duration of flow breakdown (if, and when it occurs) is much shorter than at the southern end, and both the times of flow breakdown and recovery vary greatly. The average speed during flow breakdown at the northern end is much higher than that at the southern end.

- As is expected with the morning peak traffic, queues can form and extend up the Gorge. Flow breakdown first occurs at the bottom end, as previously mentioned, and can extend all the way up on some days. Figure 5.9 shows three locations within the NATMS in the southbound direction. This figure shows that there is an approximate 10-minute lag between initial flow breakdown in the different zones, with speeds as low as 25 km/h being recorded. The bottom of the Gorge is the first to experience flow breakdown and the last to return to normal traffic flow conditions.

Figure 5.7 Morning peak southbound (southern end of Ngauranga Gorge).

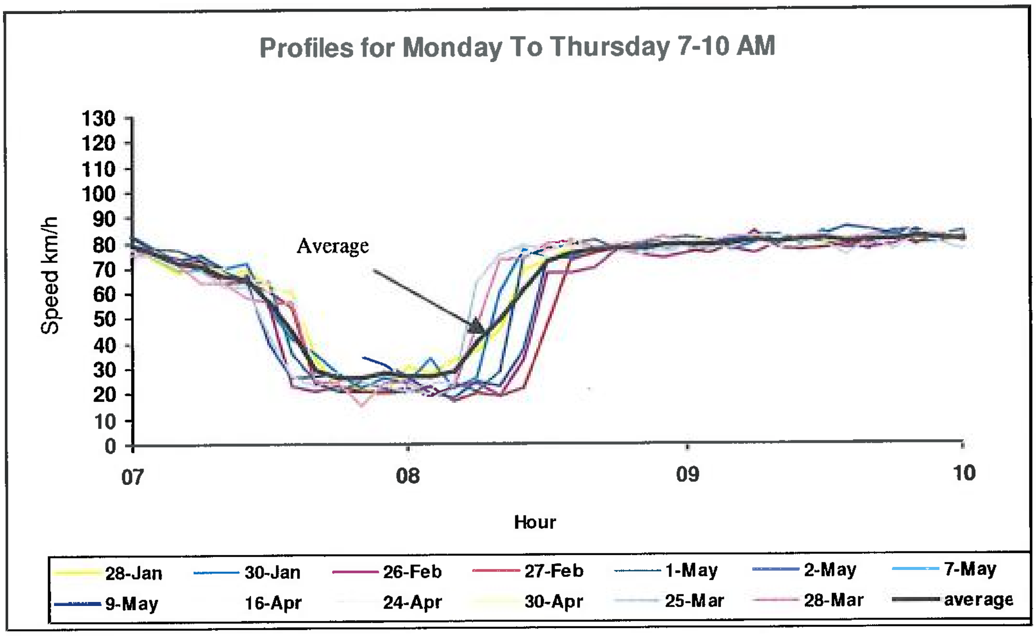


Figure 5.8 Morning peak southbound (northern end at Johnsonville).

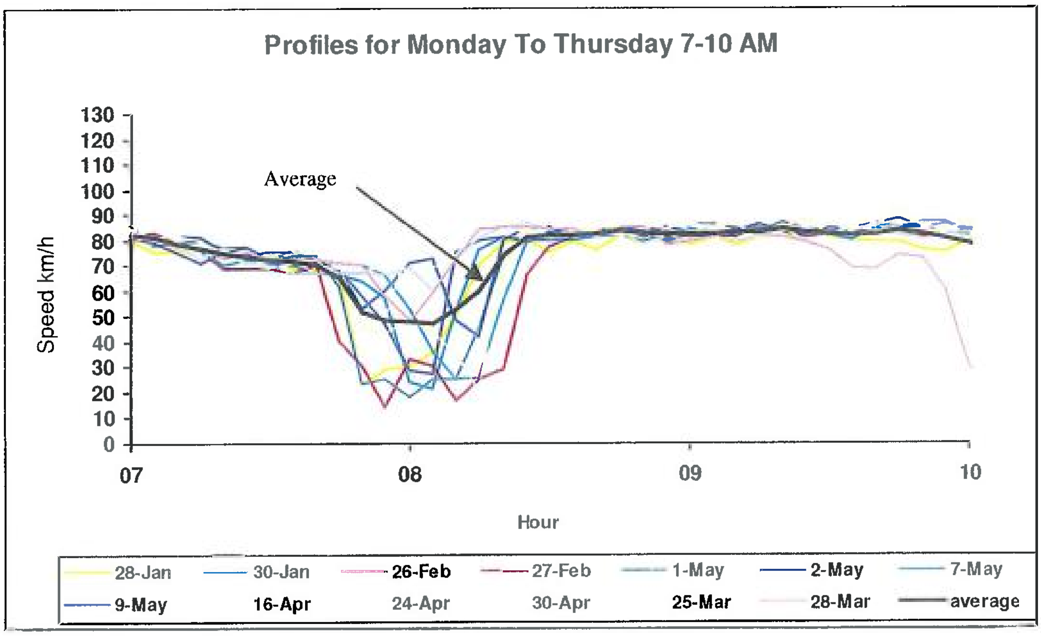
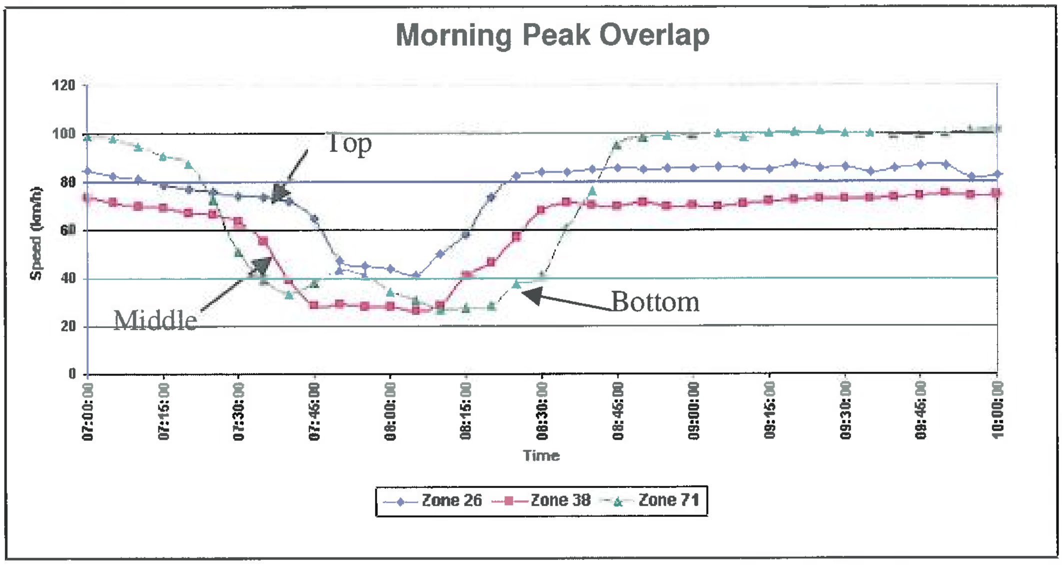


Figure 5.9 Mean southbound speed profiles for the morning peak.



5.4.2 Speed Change within Individual Zones during an Incident

The intention of this aspect of the research was to investigate if the average vehicle speed recorded in any one zone within the controlled area varied over the course of an incident.

Speeds would generally be expected to remain constant, although some reduction in speed may result at the start of an incident. Equally, as an incident continues, familiarity and advance knowledge of the incident may induce road users to increase their speeds.

Figures 5.10 and 5.11 show how vehicle speeds change over each five-minute period following the introduction of the VMSS because of an incident. Indicative traces are produced for incidents with posted speeds of 50 km/h, 60 km/h, 70 km/h and 80 km/h. The traces are formed by fitting polynomials to the speed change data points. The traces show changes in speed irrespective of lane use, although they do distinguish between northbound and southbound directions.

Figures 5.10 and 5.11 also show the effect of speed change within any zone for all types of incident classified by direction.

Traces for individual lanes are illustrated in Appendix D.

Speed data was acquired from all zones during incidents, irrespective of location within the controlled area, their duration and the type of incident.

The figures show a reduction in speed for all types of speed-constrained incidents, with the reduction continuing for 15 to 20 minutes from the introduction of the incident plan. At this point, speeds stop decreasing and show a marginal but continued increase until a point 35 to 55 minutes from the commencement of the incident.

The most marked reduction between successive 5-minute speed readings appears to be for the lower incident speed of 50 km/h. This probably reflects the fact that most vehicles have an average speed well in excess of 50 km/h and it is relatively 'difficult' to decelerate to a much lower speed and maintain this desired level, particularly when travelling on a road designed to the high standard of SH1.

Figure 5.10 Change in speed over time as an incident proceeds (southbound) Lanes 1 and 2 combined.

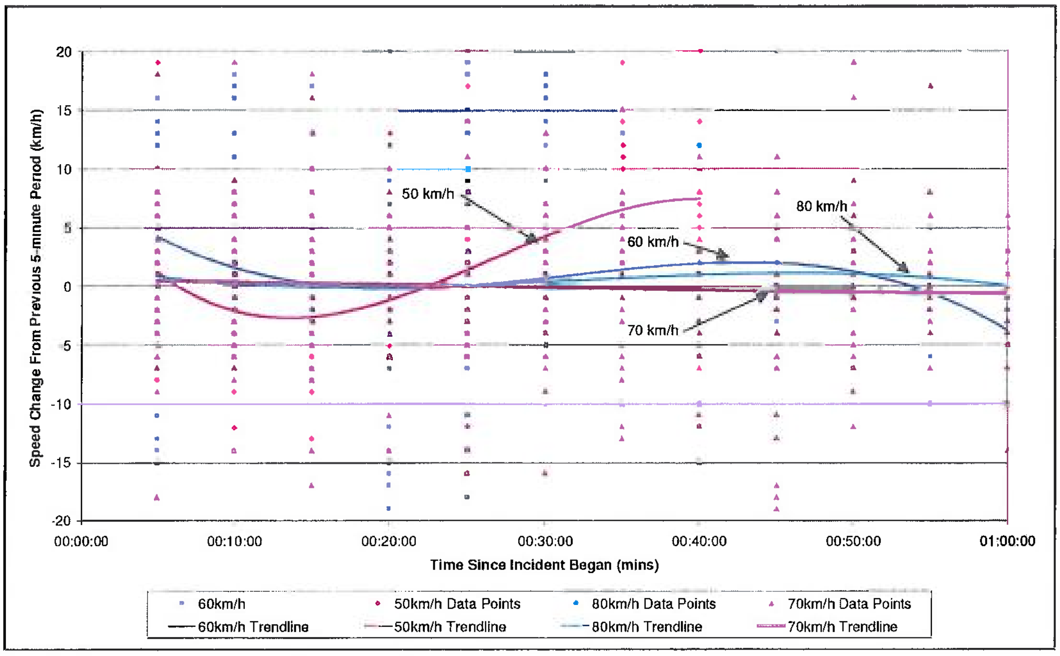
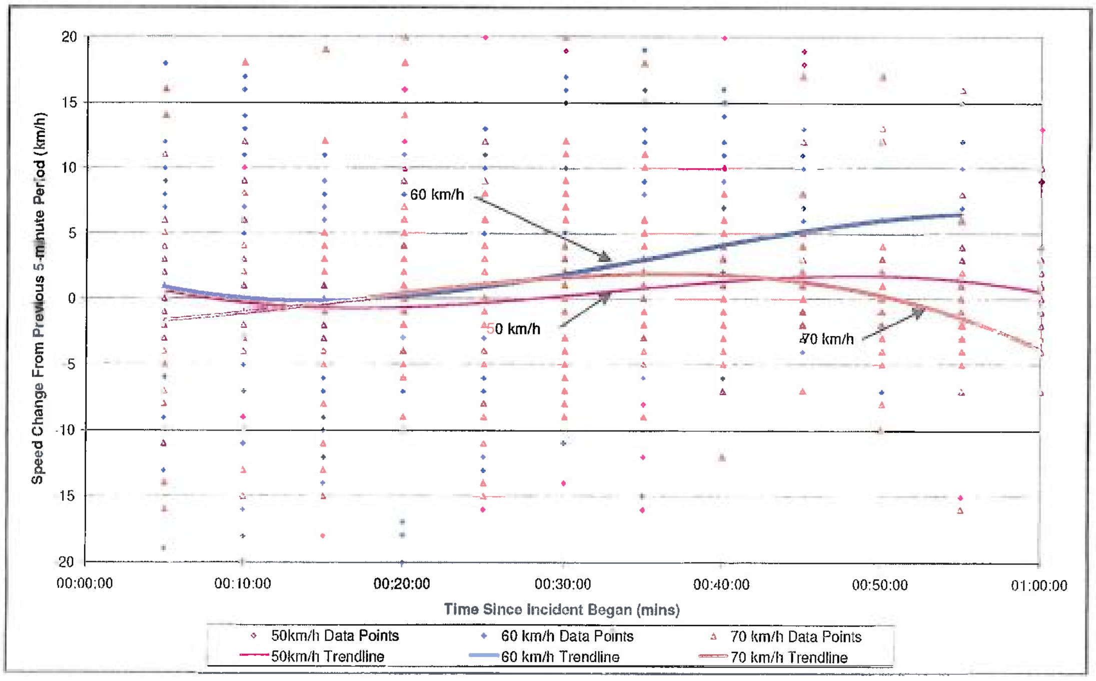


Figure 5.11 Change in speed over time as an incident proceeds (northbound) Lanes 1 and 2 combined.

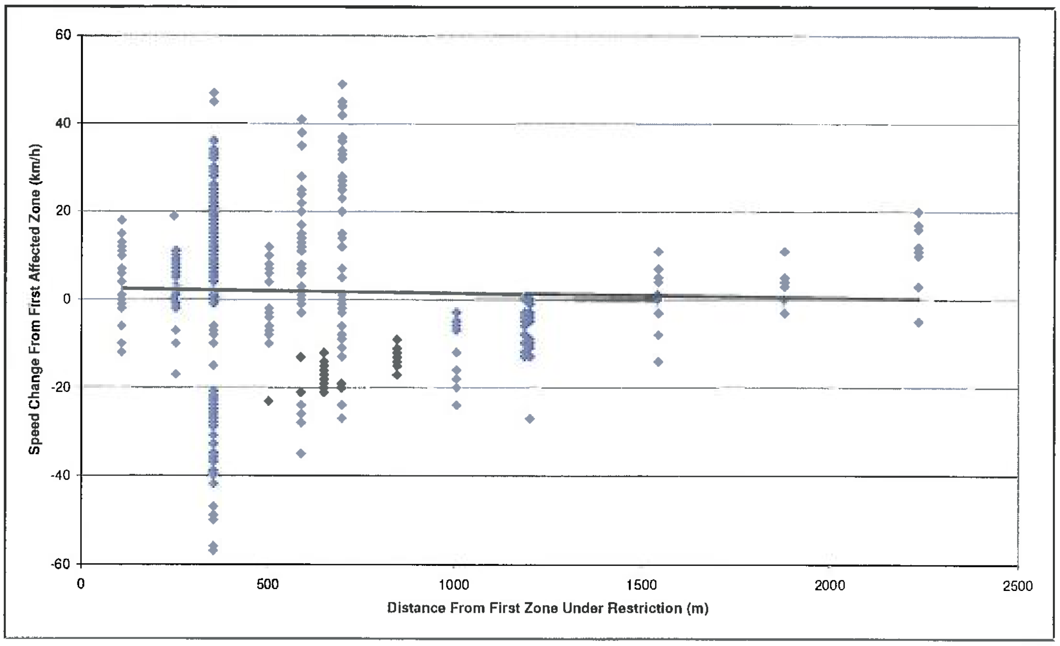


5.4.3 Longitudinal Speed Variations at Zones Affected by Incident

The purpose of this investigation was to examine how vehicle speed changed at any given time from zone to zone during an incident.

Figure 5.12 shows an example of the change in vehicle speed between the first affected zone and subsequent zones at any common time for Lanes 1 and 2 for a 70 km/h sped limit roadworks incident. The figure shows that not all road users reduce their speed on entering an affected area, with significant variability (both increases and reductions in speed) producing a wide scatter up to 750 m beyond the zone which is affected first. Vehicle speeds tend to comply with the posted speed limit between 1,000 and 2,000 m from the start of the restriction, but show some indication of rising on exiting the controlled area.

Figure 5.12 Longitudinal speed variability for Lanes 1 and 2 subject to a roadworks incident with a 70 km/h posted speed limit.



Trends for individual lanes have been developed for each type of incident subjected to different mandatory speed limits of 50 km/h, 60 km/h and 70 km/h, and are shown in Appendix E. The trends are generally inconclusive with several data sets exhibiting a rise in speed with increasing distance, which is contrary to expectation.

To be included in the above data analysis, incidents had to be at least 5 minutes in duration but were limited to one hour (as a maximum cut-off level), and had to extend over two or more adjacent longitudinal zones.

5.4.4 Diversionary Effect

Traffic volume profiles were determined for periods during incidents which offered the opportunity for diversion.

Table 5.9 provides average daily volumes on 'incident free days' for vehicles exiting via the Hutt Off-ramp, using traffic volume data acquired from the data collection cameras at Johnsonville and the Transit telemetry site.

Table 5.9 Hutt Off-ramp daily traffic volumes.

Period (all day)	Daily Traffic Volumes on Hutt Off-ramp
Monday to Thursday	11179
Friday	12410
Saturday	8600
Sunday	7088

Table 5.10 Diversionary flows to Hutt Off-ramp during incidents.

Period	Total Volume during Incidents	Equivalent Volume during Normal Periods	Number of Occasions	Percentage Increase	Weighted Overall Percentage Increase
Monday to Thursday	3626	2499	11	45	40%
Friday	855	867	1	-1	
Saturday	1499	1338	1	12	
Sunday	861	750	3	15	

Table 5.10 indicates the volumes using the Hutt Off-ramp during incidents and also over an equivalent period during 'incident-free' days. The increase in traffic ranges from –1% to 45% depending upon the study period (i.e. a decrease of 1% to an increase of 45%).

When the numbers of incidents during specific periods are taken into account, the overall increase in volume using the Hutt Off-ramp amounts to 40%.

The figures in Appendix F present the traffic volume profiles for the Hutt Off-ramp during both incidents and incident-free periods, illustrating the rise in volume during times when incidents occur.

5.4.5 Speed Changes during Wet Weather Road Conditions

During times of inclement weather, Zones 70 and 71 have their posted speeds reduced from 100 km/h to 80 km/h.

The opportunity was taken to assess the difference in speeds between base conditions and those during wet weather conditions, using speeds recorded at Zones 65 and 66 which are located immediately upstream of Zones 70 and 71 respectively. At these zones, the VMSS remain at 80 km/h during periods of wet weather.

The data pertaining to the four zones is presented in Table 5.11. The results suggest that:

- A marked reduction in speed occurs during wet weather at the four zones investigated, with speeds falling by between 3.5 and 10.1 km/h.
- The standard deviation of speeds increases during wet weather conditions but the 85th percentile speed drops by between 2.0 and 6.0 km/h.
- Zones 70 and 71 show an average reduction of 4.5 km/h when subjected to a combination of wet weather conditions and a reduction in VMSS posted speed from 100 km/h to 80 km/h.

Table 5.11 Effects of wet weather incident plans.

Measure	Unit	Lane 1				Lane 2			
		Zone 66		Zone 71		Zone 65		Zone 70	
		Base (80 km/h)	Wet Weather Days (80 km/h)	Base (100 km/h)	Wet Weather Days (80 km/h)	Base (80 km/h)	Wet Weather Days (80 km/h)	Base (100km/h)	Wet Weather Days (80 km/h)
Mean	km/h	93.7	83.6	95.8	90.4	87.6	78.6	97.7	88.2
Standard deviation	-	13.6	16.5	15.9	18.8	12.5	14.6	14.7	16.8
85th Percentile Speed	km/h	100.0	94.0	106.0	104.0	94.0	88.0	100.0	99.0
Percentage Exceeding 80km/h	%	95	78	94	85	93	65	93	87
Reduction in Speed	km/h	10.1		5.4		9.0		3.5	
Increase in Mean Speed Between Adjacent Zones - Base		2.1				10.1			
Increase in Mean Speed Between Adjacent Zones - Wet Weather		6.8				9.6			

6. Specific Outcomes of Research

The provision of 66 detection zones within NATMS, together with the technology facilitating the acquisition of vehicle speed data at time intervals of 5 minutes, has ensured the availability of significant amounts of data enabling a detailed study of the effect of VMSS on driver behaviour during both normal and incident-constrained conditions.

Section 5 of this Report provides an insight into the extent and use of the data. Although in line with most research, some of the resulting figures and trends are unconvincing, producing anomalies which are difficult to explain rationally.

Consequently, the research recorded in this Report attempts to specifically answer the principal issues associated with the original objectives of the study.

The discussion below, in the form of a series of questions with responses, summarises the main findings and compares them, wherever possible, with the results found from experience overseas.

6.1 Compliance with Mandatory Speed limits

Q: Do road users comply with the mandatory speed limits displayed by the VMSS during both incident-free and incident-constrained conditions?

Tables 5.1 and 5.2 show relatively high exceedance levels for 80 km/h incident-free conditions (33% to 56%), with generally higher values at weekends. Figures 6.1 and 6.2 support these findings, with 40% (southbound) to 49% (northbound) of vehicles exceeding the posted speed limit.

Exceedance levels for 100 km/h incident-free posted speed limits are relatively low, ranging from 1% to 11%. This is considered more to reflect the difficult topography, gradient, and varying highway cross-section, which severely restrict the speed of vehicles.

However, if these figures for incident-free conditions are disturbing, then the levels of exceedance recorded for incident conditions are of major concern.

Figures 6.3 and 6.4 show speed measurements recorded during various types of incidents, with levels of exceedance of posted speed ranging between 40% and 87%. This is not surprising given the high average speeds recorded during different types of incidents and reflected in Table 5.8. Clearly, road users are largely ignoring the VMSS or failing to reduce the speed of their vehicles to that indicated. This is particularly evident for 'low-speed' incidents (i.e. 50 km/h and 60 km/h) with only a 70 km/h speed limit posted for an incident showing some degree of adherence and compliance by road users.

Figure 6.1 Accumulative speed distribution for base case for Lanes 1 and 2, southbound.

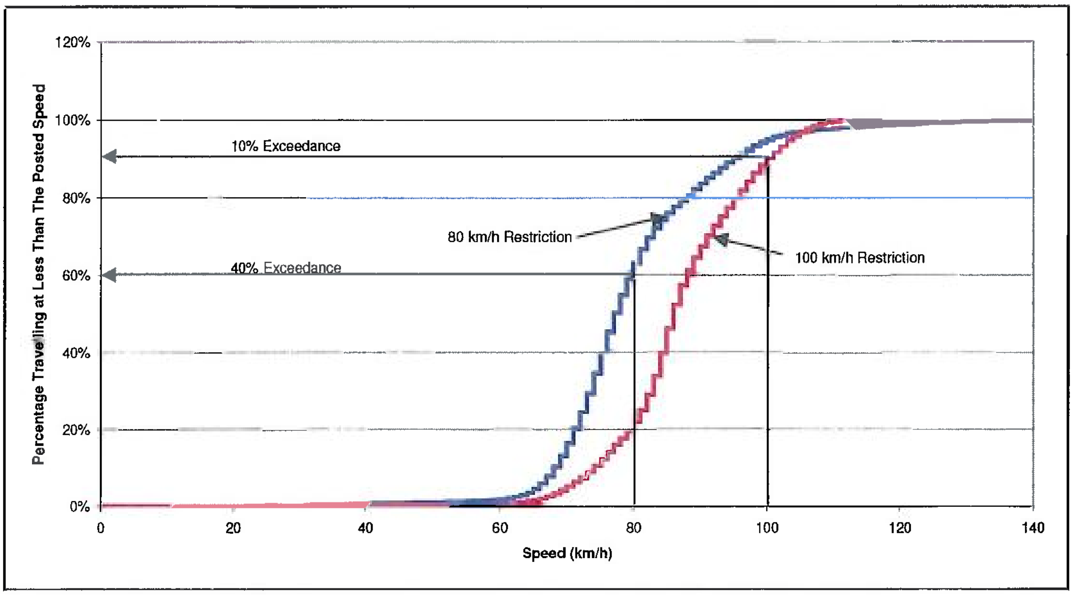


Figure 6.2 Accumulative speed distribution for base case for Lanes 1 and 2, northbound.

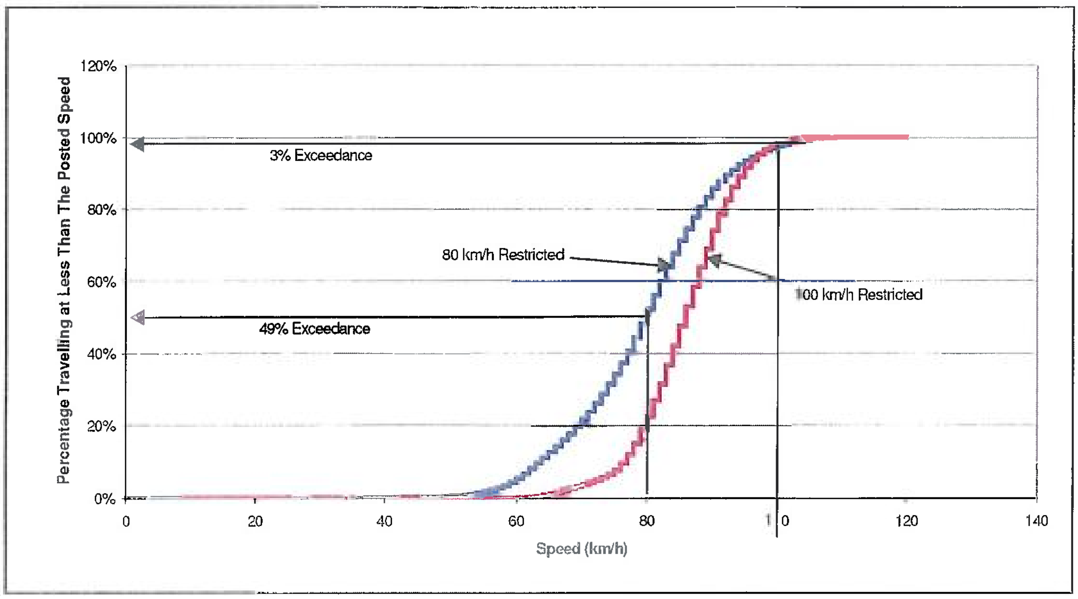


Figure 6.3 Accumulative speed distribution for incidents for Lanes 1 and 2, northbound.

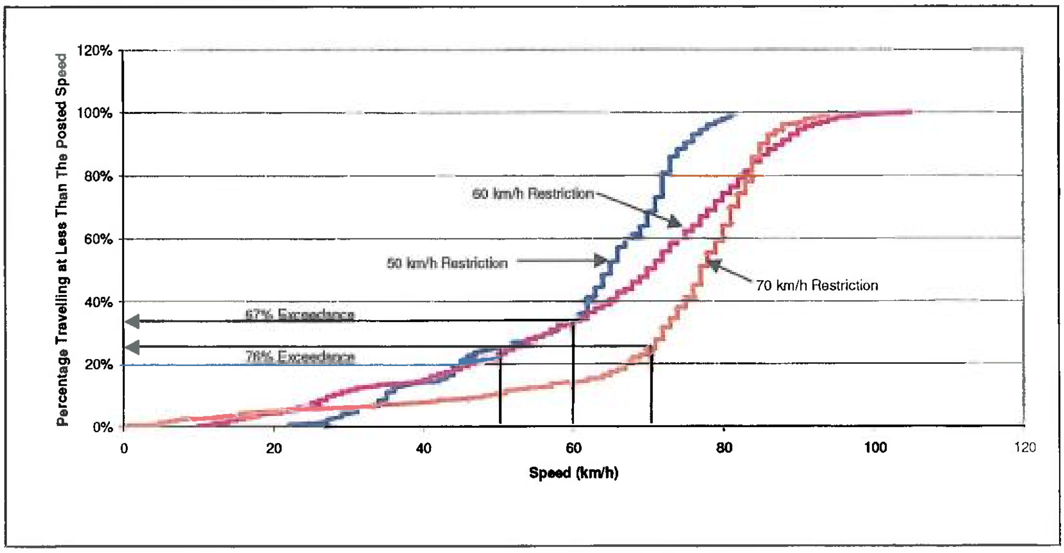
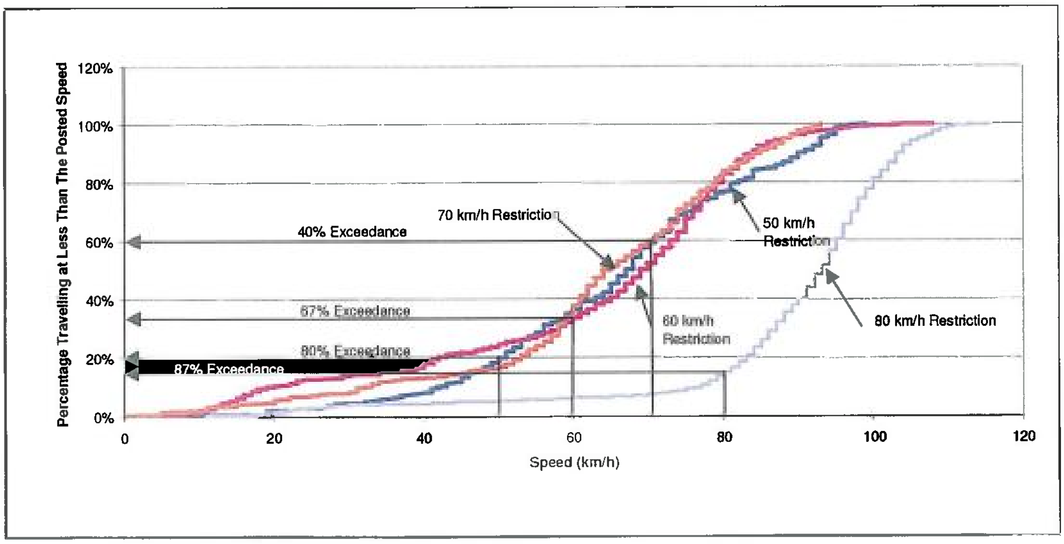


Figure 6.4 Accumulative speed distribution for incidents for Lanes 1 and 2, southbound.



It should be remembered, in making the above statements, that all lanes remained open for use. Also, there was considerable variation in the number of speed measurements recorded during different types of incident, and the incidents were not equally distributed by direction.

6.2 Vehicle Speed Variance

Q: Is there any similarity between the way that road users respond to an 80 km/h posted speed limit during incident and incident free-conditions?

Quite categorically no – at least, not from our findings. There is a sizeable exceedance (87%) of the 80 km/h incident-posted speed limit. However, this coincides with sections of NATMS that are normally signed at 100 km/h during incident-free conditions, the speed to which regular users will be accustomed. Consequently, we are not exactly comparing 'apples with apples'.

The actual area reduced from 100 km/h (free flow conditions) to 80 km/h during wet weather is in the southbound direction, at the base of the descent through Ngauranga Gorge and immediately before the SH1/SH2 merge. As such, it is one of the locations where higher speeds can be expected.

Q: Do road users vary their speed throughout an incident-affected area?

Our results indicate that they do. There appears to be significant variation in speed over the first 750 m of an area under an incident speed control plan (± 40 km/h) with this being restricted to –20 to +10 km/h over the subsequent two-thirds of the controlled section. There is some evidence of an increase in speed (0 to 20 km/h) at the point of exit.

Q: At any particular point in the NATMS, do speeds change over time when under incident management control?

Our data indicates that vehicle speeds decrease over the first 15 minutes of an incident, and then gradually increase during the period 35 to 55 minutes from the start of the incident.

The magnitude of each successive 5-minute increase or reduction in speed is most marked for incidents necessitating a low posted speed limit (i.e. especially 50 km/h).

Q: Do the speeds recorded for different incident types under the same posted speed limit exhibit significant variation? Is there any evidence to suggest that the speeds recorded in the median and adjacent lanes differ from one another and show distinct differential behavioural characteristics?

In determining parameters to quantify results, measures of mean, standard deviation and 85^{th} percentile speed are generally quoted in most assessments of road user behaviour relating to normal and incident conditions. This approach enables means to be compared, with an indication of the variability of the data being provided through use of the standard deviation and 85^{th} percentile measures.

However to make meaningful statistical comparisons is very difficult. First consider that the actual speed measurements are **not** individual measures – they are average speeds based on an assessment of a fixed buffer of 50 speed measurements. The 'average' speeds have then been deposited in databases according to time of day, direction and lane use, prior to any further analysis. Additional evaluation involved taking an 'average' or mean of the previously averaged data. Consequently, it is clear that any detailed statistical investigation of the resulting data is both meaningless and flawed.

When assessing speeds during times of incidents, time of day is ignored, with the results categorised only by direction and lane.

At a more disaggregate level, the speed data results (for incidents) have been examined using the Statistical Package for Social Scientists (SPSS) with the actual distributions often showing the data to be skewed or not following a normal distribution profile. This lack of 'normality' determines the forms of statistical tests to be applied, either parametric or non-parametric.

Non-parametric tests (Mann-Whitney and the Kolmogorov-Smirnoff tests) did indicate significant difference in mean speeds by lane. This was true for breakdowns and crashes, but the lack of significant data relating to other forms of incident made further statistical analysis meaningless.

More work could be performed in this area but the manner in which the equipment assessed speed measurements raises doubts over its worth.

6.3 Diversionary Effect of Hutt Road

Q: Is there a discernible diversionary effect and use of Hutt Road due to incidents downstream of NATMS?

Yes, the effect is quite marked. Table 5.10 shows that the estimated vehicle flow on the Hutt Road Off-ramp experiences a –1% (i.e. actual decrease) to 45% (increase) in traffic volume. Overall the average percentage increase is around 40%, with the highest diversionary effect being during weekdays.

The above results indicate that road users are taking the opportunity to divert to the local road network to avoid the possibility of suffering significant delay further downstream.

This 'natural' diversion is effective, provided adequate parallel routes with sufficient capacity exist to accommodate the diverted traffic.

6.4 Weather Effects

Q: Is the weather effect able to be identified within speeds measured during incidents?

Wet weather incident plans are only introduced to southbound road users within the 100 km/h zones immediately north of the SH1/SH2 merge. During poor weather the VMSS are reduced from 100 km/h to 80 km/h. This provides the opportunity to compare 'wet weather speeds' with speeds recorded during normal flow conditions, using data acquired from the adjacent 80 km/h zones.

The data presented in Section 5.4.5 are rather contradictory, if trends are examined by lanes and between zones. However, all individual zones do reveal a fall in speed during wet weather conditions. The magnitude of this reduction ranges between 5.5 km/h and 10 km/h.

For the 100 km/h incident-free zones (Zones 70 and 71), the reductions in speed reflect the combined effect of wet weather and the change in the posted VMSS from 100 km/h to 80 km/h.

6.5 Effects of Introduction of VMSS

Q: Can the results of the research be viewed as entirely due to the introduction of different speeds shown by the VMSS?

Certainly not. It is recognised that within NATMS, the sole effect of the VMSS cannot be considered in isolation from that of the various and frequently positioned VMS. Other characteristics of NATMS make this exercise even more onerous and subjective. These include the daunting topography, demanding alignment (including speed constrained curves), varying highway cross-section, and frequent provision of on- and off-ramps causing much merging, diverging and weaving.

Experience worldwide supports this view. However, it is the complementary effect of **all** of the various architecture features of ATMS, which combine to offer the benefits associated with ATMS. Research from the UK (Harbord 1998) has shown that on the M25 orbital motorway road users strongly rely on the VMSS for advice on traffic conditions likely to be experienced during their travel, judging from the sizeable number of complaints when the VMSS were voluntarily switched off. They were perceived by many road users as providing vital information on road or traffic conditions, together with guidance as to a suitable speed at which to drive given the prevailing conditions. It appears that they offer some degree of assurance to road users.

Q: Is there evidence to suggest that VMSS can regulate speeds during incidents better than Advisory Speed Signs?

We have no clear evidence from overseas experience to categorically state that VMSS are preferable to Advisory Speeds Signs for improving adherence to specified speed limits.

Certainly the M25 evidence suggests a 'buy in' or acceptance of active enforcement is needed before an ATMS with VMSS can work efficiently and produce the anticipated or expected results. Major improvements in traffic flow (7%) have been claimed when at the peak of its designed capacity because the amount of variability in speed is reduced and also more consistent headways are produced (Harbord 1998).

From our research, VMSS do reduce speeds in certain instances although not below the posted speed, but nevertheless can assist road users in guiding them through incidents at appropriate speeds.

It is our opinion that VMSS can work satisfactorily but **only** with active, visible enforcement which road users accept and adhere to.

Q: Should VMSS be employed if further extensions are made to the Wellington ATMS?

The Police issued 7459 tickets for exceeding the speed limit of 80 km/h within the central section of NATMS in 2001, based upon the photographs taken of offending vehicles by the static speed camera. Our evidence from speed measurements recorded by the AIDs at all the various zones, would suggest that, judging by the level of exceedance of prevailing posted speed limits, considerably more offences are committed.

Unless a national policy decision is forthcoming regarding the inappropriateness and unsuitability of VMSS, they should be utilised in any further extensions of ATMS, solely because drivers are now familiar with them.

The overwhelming tendency, as shown by the results of this research is for drivers to exceed the posted speed limits during incidents within NATMS. Therefore the implementation of VMSS against Advisory Signs would appear to give limited benefit, unless proactive and continuous enforcement is provided at similar levels as to that of, for example, the M25 in the UK. This would necessitate a considerable additional financial investment.

7. Recommendations for Future Research

The focus of this particular piece of research has centred on the way in which road users respond to the posted speeds indicated by the VMSS during 'incident-free' conditions and occasions when incident management plans are introduced.

Consequently, the findings are not intended to be used for the purpose of evaluating, or for seeking justification for introducing, ATMS. However, it would clearly be beneficial if the data captured and results determined could, in some way, be linked and used in an evaluation process, rather than be used for the purpose of solely quantifying driver behaviour.

During the course of the research, two potential uses of the data came to light. These were concerned with determining the amount of lost time associated with different types of incident, and also how the Ngauranga Gorge data could be employed elsewhere to predict incident rates.

7.1 Lost Time Caused by Incidents

The speed data acquired during the data collection phase of the research has been utilised to produce speed profiles by time of day during normal conditions. These are referred to as base profiles or speed profiles free from incidents.

The format of the speed profile diagrams resemble those presented in Figures 5.7, 5.8 and 5.9, except that they all would show examples of speed reductions caused by incidents. Such an example is reproduced in Figure 7.1 which shows the effect of an incident on vehicle speed. In this particular case, an incident (due to roadworks) necessitated a reduction in posted speed limit from 100 km/h to 50 km/h, and then to 80 km/h before returning to 100 km/h.

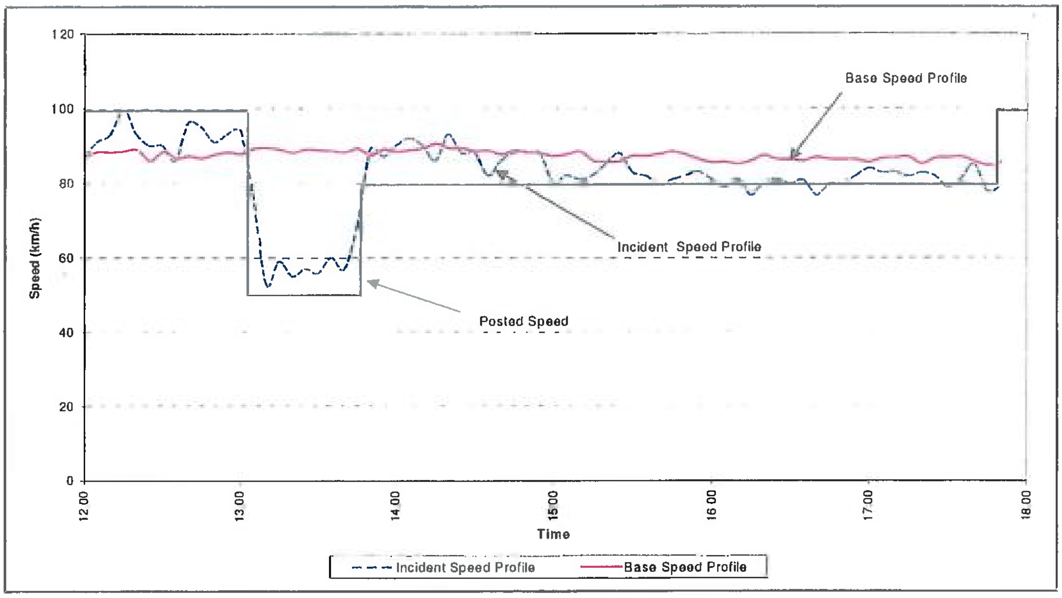
To provide something of value from such diagrams involves manipulating the indices or units to give either veh h/h or simply veh h, both of which equate to the amount of time taken by incident occurring within an effected area.

The process would involve:

(1) Determining the area of the speed profile diagram between a 'base or normal' profile and that during an incident. The area involved is a measure of $\left(\frac{km}{h} \times h\right)$,

(2) Extending (1) to give lost time by factoring or multiplying the number of vehicles (or exposure) and the length affected.

Figure 7.1 Speed profile related to an incident.



The equation becomes:

$$(Speed \times \text{ } Duration \text{ } of \text{ } Incident \text{ } from \text{ } Diagram) \times Traffic \times \frac{1}{Length}$$

or in units

$$\left(\frac{km}{h} \times h\right) \times veh \times \frac{1}{km}$$

$$= \frac{veh.h}{h}$$

This process would be arduous as two speed profiles for each zone affected would have to be utilised each time an incident resulted. In addition, traffic volume, also by zone affected, would be required to correspond with each measurement of speed. This is the only parameter which was unable to be measured due to the limited capabilities of the equipment within the research.

An alternative means of determining lost time, but which is very approximate, is to take the information relating to frequency and average duration of incidents as given in Tables 5.5, 5.6 and 5.7 and extrapolate them to extend over a full year. Again with some allowance for exposure or traffic volume, a measure of annual lost time due to incidents could be established. It should be pointed out that the result – irrespective of the method used to determine it – **only** applies to the Ngauranga Gorge and reflects the topography, highway cross-section, and prevailing traffic for that location.

7.2 Relationship between Incidents and Traffic Flow

The Transfund Project Evaluation Manual (1997) provides references to procedures for assessing expected crash rates, used in evaluating proposals for improvement.

It would be useful to develop levels of incidents for motorways carrying different levels of traffic. The assumption is made here that incident management systems such as NATMS would only be introduced on motorways, although they may eventually have a role on high volume urban and rural arterials.

With the significant data on incidents, incident rates (in terms of incidents per veh km) could be established for different types of road.

An alternative to this would be to try and produce a relationship linking $\frac{V}{C}\left(ie\frac{Volume}{Capacity}\right)$ against incidents, similar to a traditional speed-flow relationship.

The specific aim would be to predict the level of incidents for any given V/C ratio. However, this assumes that, for any given type of road, the V/C against incident relationship would behave similarly. Problems modelling crashes or crash rates with traffic volume would suggest that it is unlikely to be successful and/or may be difficult to prove.

7.3 Future VMSS Research

Given the relatively short length of NATMS and the varying topography, highway cross-section and underlying effects of complementary VMS, pursuing any further additional work on the effects of VMSS would appear pointless.

However, given a controlled environment (e.g. similar to the M25), it would be particularly interesting to investigate:

- the effects of VMSS without the complementary VMS;
- a wider range of speed constraint reflecting varying type of incidents;
- the effect of the active enforcement of VMSS against those systems utilising VMSS **without** visible levels of policing or methods of enforcement;
- further examples of the combined effects of incidents plus inclement weather, to substantiate whether the speed reduction is more marked when both are implemented, against the sole use of speed reductions resulting from an incident but **without** the weather factor.

In terms of extensions to NATMS or future application within New Zealand, without effective and active enforcement, VMSS would appear to offer little additional benefit over Advisory Speed Signs. However, as they already exist within NATMS, any extension to the Wellington Network may want to consider VMSS for compatibility and familiarity reasons.

8. References

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Appendices

A Zone Arrangement within ATMS

B Traffic Count Data from VIP Cameras and Transit's Telemetry Site at Ngauranga Gorge

C Vehicle Speeds during Normal Flow Conditions

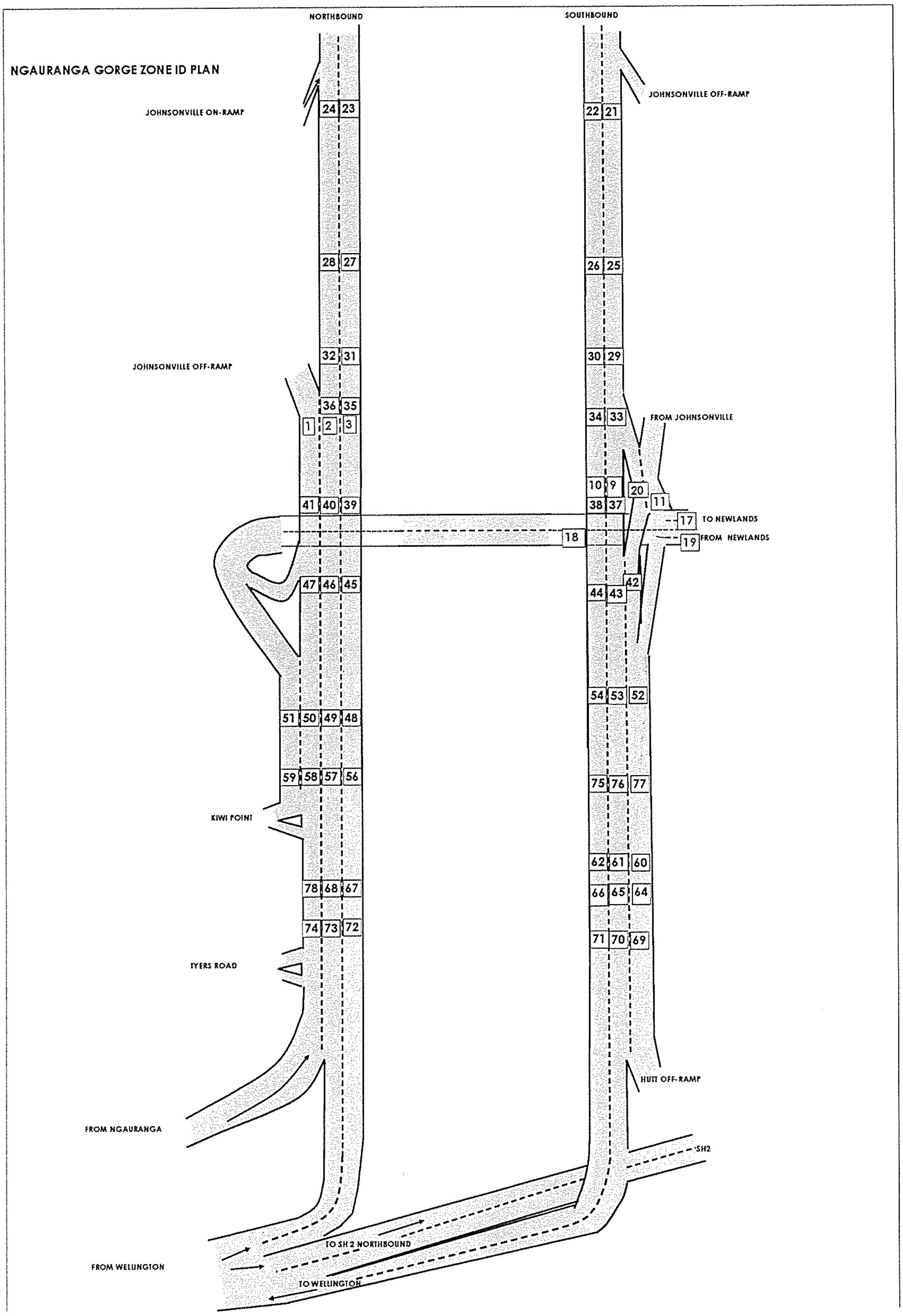
D Speed Change within Individual Zones Affected by Incidents

E Longitudinal Speed Variation through the Controlled Area

F Hutt Off-ramp Diversionary Flow Profiles

Appendix A

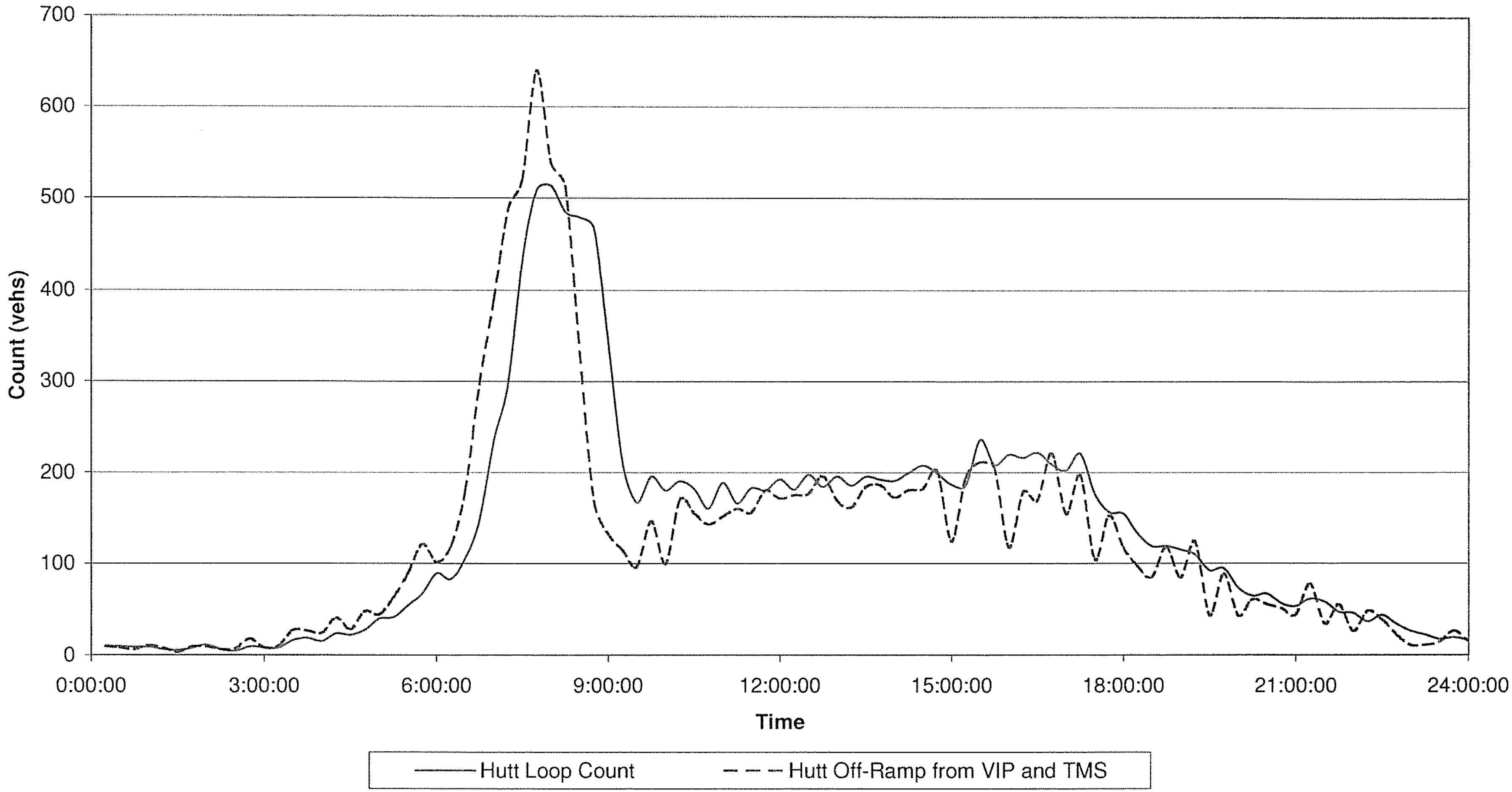
Zone Arrangement within NATMS

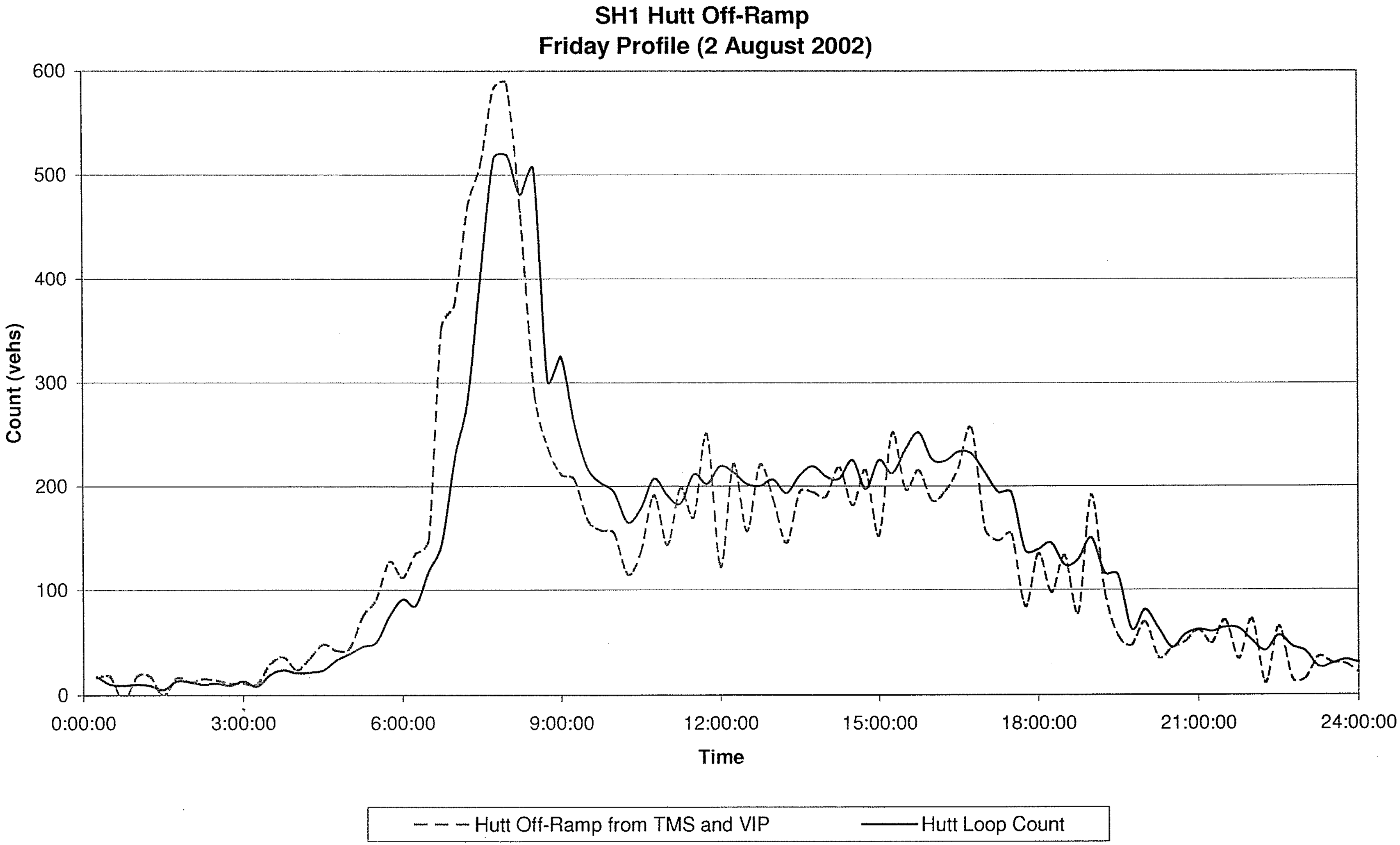

NGAURANGA GORGE ZONE ID PLAN
NORTHBOUND
SOUTHBOUND
JOHNSONVILLE ON-RAMP
JOHNSONVILLE OFF-RAMP
JOHNSONVILLE OFF-RAMP
FROM JOHNSONVILLE
TO NEWLANDS
FROM NEWLANDS
KIWI POINT
TYERS ROAD
HUTT OFF-RAMP
SH2
FROM NGAURANGA
FROM WELLINGTON
TO SH 2 NORTHBOUND
TO WELLINGTON

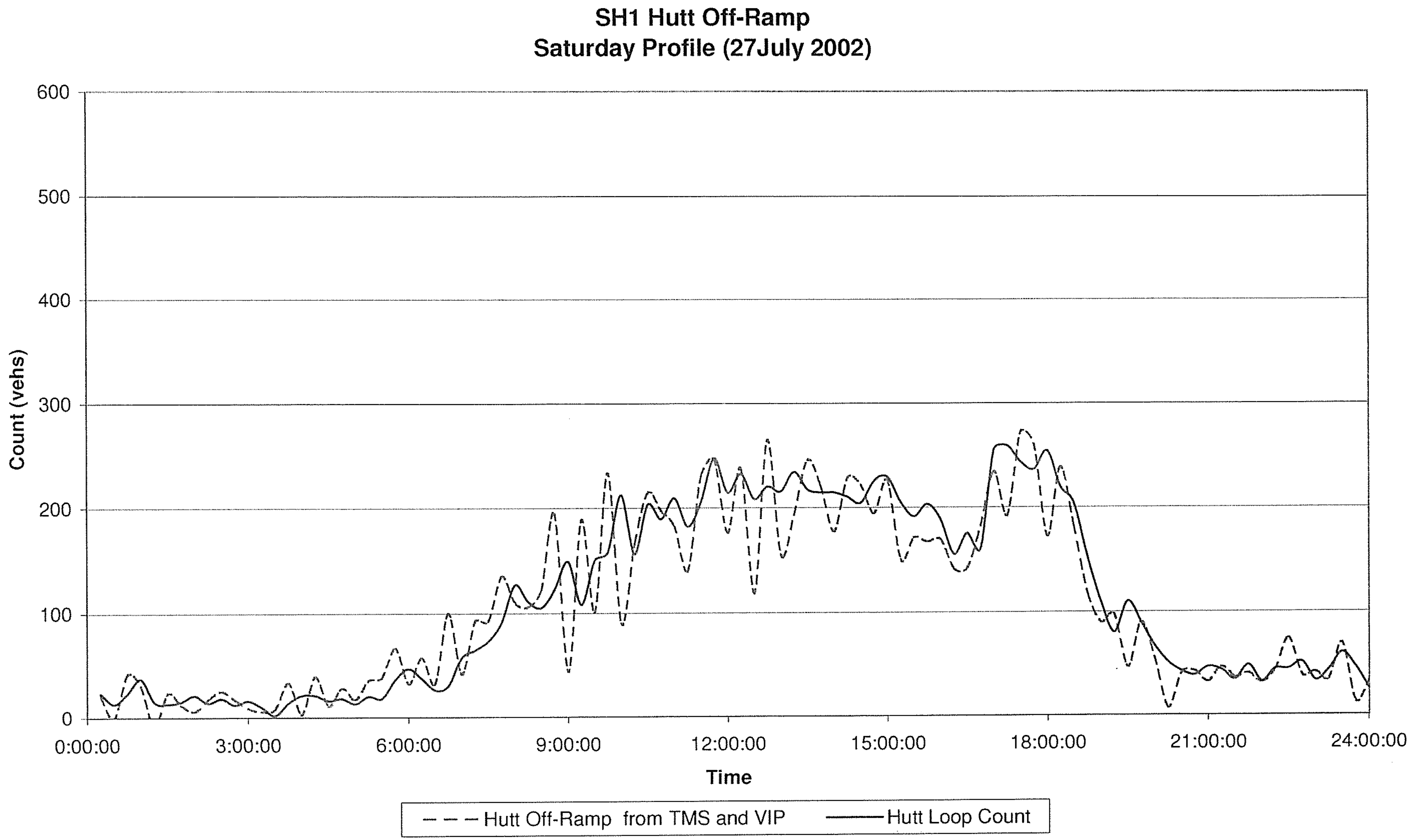
Appendix B

Traffic Count Data from the VIP Cameras and Transit's Telemetry Site at Ngauranga Gorge

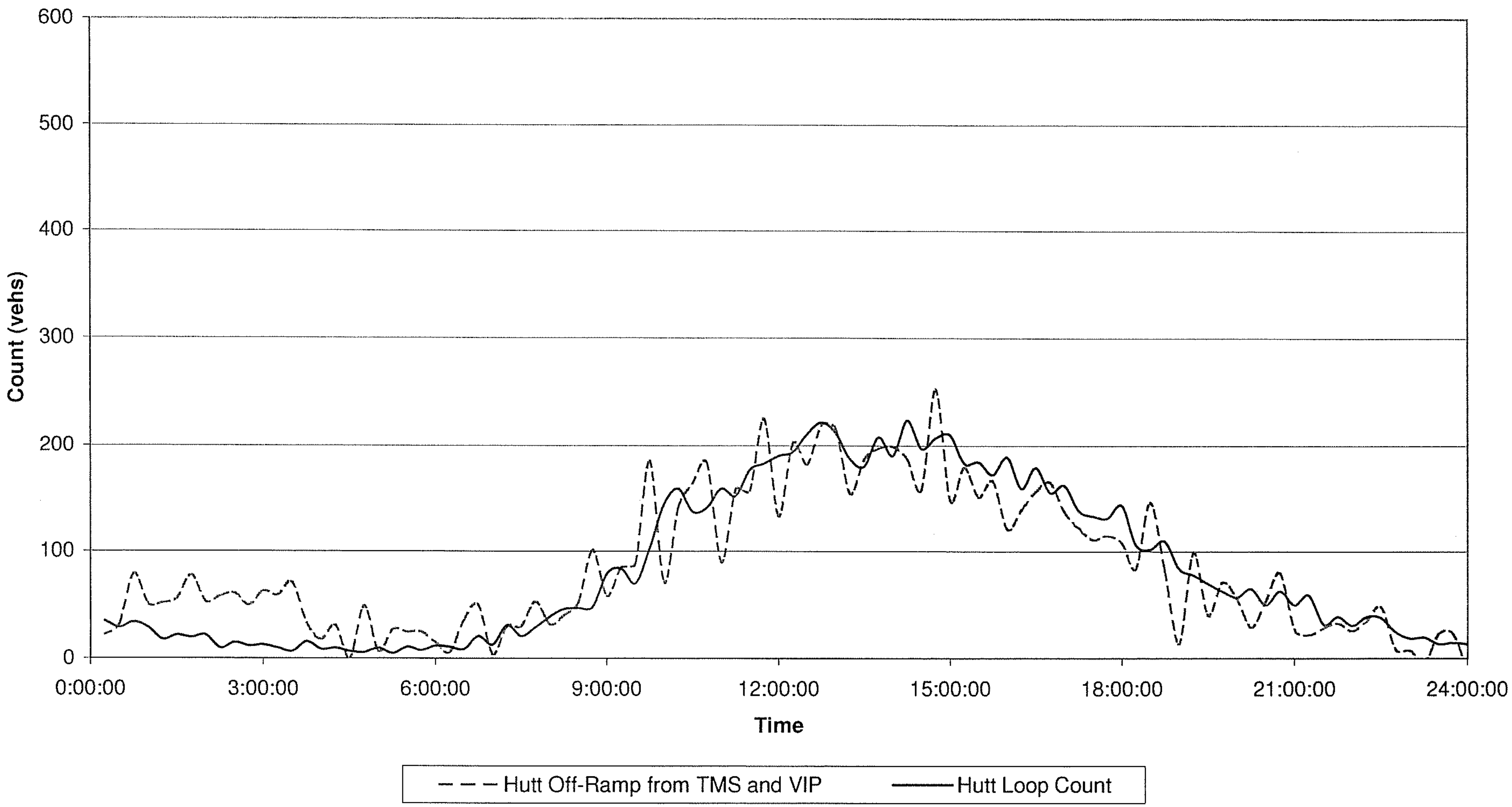
SH1 Hutt Off-Ramp
Monday to Thursday Average Daily Profile (29 July to 1 August 2002)




SH1 Hutt Off-Ramp
Friday Profile (2 August 2002)
Count (vehs)
600
500
400
300
200
100
0
0:00:00
3:00:00
6:00:00
9:00:00
12:00:00
15:00:00
18:00:00
21:00:00
24:00:00
Time
Hutt Off-Ramp from TMS and VIP
Hutt Loop Count


SH1 Hutt Off-Ramp
Saturday Profile (27July 2002)
600
500
400
300
200
100
0
Count (vehs)
0:00:00
3:00:00
6:00:00
9:00:00
12:00:00
15:00:00
18:00:00
21:00:00
24:00:00
Time
Hutt Off-Ramp from TMS and VIP
Hutt Loop Count

SH1 Hutt Off-Ramp
Sunday Profile (28 July 2002)



Appendix C

Vehicle Speeds during Normal Flow Conditions

Monday to Thursday Base Profiles

	Monday to Thursday																									
	Southbound Lane 1													Northbound Lane 1												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean	80.1	89.1	80.3	89.2	40.1	73.3	80.6	81.8	90.0	81.1	91.2	80.4	88.8	81.0	88.0	77.9	83.3		81.2	91.4	84.3	94.0	81.1	88.8	81.3	84.9
St. Dev.	10.4	10.2	10.2	6.5	22.1	14.9	17.2	8.7	9.8	9.1	9.6	9.2	9.3	11.2	7.2	11.4	6.8		12.6	5.5	10.8	4.5	9.5	5.7	10.2	5.8
85th Perc.	92.0	99.0	93.0	97.0	70.0	85.0	97.0	92.0	103.0	92.0	104.0	93.0	99.0	92.0	96.0	90.0	90.0		91.0	97.0	95.0	98.0	91.0	95.0	92.0	91.0
% Exceed	41	13	39	5	23	29	12	50	22	45	22	35	9	54	3	44	0		67	3	65	7	53	1	52	1

	Monday to Thursday																									
	Southbound Lane 2													Northbound Lane 2												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean	75.7	83.7	76.6	84.2	37.0	69.6	77.1	76.5	84.4	76.0	85.2	75.9	84.2	75.1	82.4	71.9	77.9		77.5	85.3	79.0	87.8	74.9	83.3	73.9	79.8
St. Dev.	9.4	10.9	9.2	9.7	20.7	13.1	13.9	7.9	10.4	8.6	11.0	8.6	10.4	11.3	7.2	11.7	6.8		9.6	5.0	10.9	4.5	10.4	6.2	11.1	6.8
85th Perc.	86.0	96.0	88.0	95.0	64.9	80.0	91.0	86.0	97.0	87.0	99.0	88.0	95.0	87.0	89.0	84.7	85.0		86.0	91.0	90.0	92.0	86.0	89.0	86.0	86.0
% Exceed	26	5	30	2	20	14	1	25	7	23	11	23	3	33	0	23	0		39	0	47	0	32	0	29	0

	Monday to Thursday																									
	Southbound Lane 3													Northbound Lane 3												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean	71.3	92.7	69.7	91.8	33.4	64.6	82.3	72.7	94.2	74.2	95.0	73.0	94.8	67.6		64.6			66.2		68.7		67.4		70.8	
St. Dev.	12.4	8.8	12.4	6.0	19.4	15.5	19.7	10.8	7.0	11.4	5.0	12.2	5.7	12.3		12.8			10.5		11.5		13.4		12.1	
85th Perc.	88.0	99.0	86.0	97.0	57.0	82.0	97.0	88.0	100.0	90.0	100.0	90.0	100.0	80.0		79.0			76.0		79.0		80.0		84.0	
% Exceed	29	9	26	5	11	18	3	30	12	32	11	32	13	14		12			8		13		13		23	

	Monday to Thursday																									
	Southbound Lane 4 N/A													Northbound Lane 4												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean														58.8		56.3			56.7		60.0		62.3		60.3	
St. Dev.														18.2		16.1			20.2		19.8		15.9		18.4	
85th Perc.														77.0		73.0			76.0		79.0		78.0		79.0	
% Exceed														9		6			9		11		9		10	

Friday Base Profiles

	Friday																									
	Southbound Lane 1													Northbound Lane 1												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean	81.5	90.1	81.7	89.6	45.2	74.3	84.5	83.7	92.7	81.6	91.3	82.4	89.8	80.9	87.9	77.8	83.9		82.7	91.5	84.2	92.8	80.7	88.7	80.6	85.0
St. Dev.	11.5	9.2	10.9	7.6	25.1	16.9	14.0	9.6	9.3	9.9	8.8	10.3	6.8	11.1	6.2	12.5	6.0		11.5	4.5	10.3	3.8	9.2	4.5	9.2	4.9
85th Perc.	94.0	101.0	95.0	100.0	75.0	88.0	101.0	95.0	105.0	93.0	103.5	94.1	97.0	92.0	94.0	90.0	90.0		93.0	96.0	96.0	97.0	90.0	93.0	90.0	90.0
% Exceed	46	17	42	10	32	32	17	56	29	47	23	47	7	51	1	42	0		62	2	63	3	47	0	47	0

	Friday																									
	Southbound Lane 2													Northbound Lane 2												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean	76.1	83.9	76.6	84.3	42.7	69.0	77.8	77.8	85.0	75.7	84.4	77.1	84.8	74.8	82.7	71.2	79.4		78.8	86.1	78.8	87.0	72.4	82.8	73.5	80.2
St. Dev.	11.0	10.2	10.4	9.1	23.0	15.4	13.4	9.5	9.9	10.2	9.9	9.7	9.2	11.2	6.3	11.9	6.4		9.3	4.6	10.2	4.2	11.1	5.4	10.4	5.9
85th Perc.	87.0	96.0	88.0	94.0	71.1	81.0	93.0	89.0	98.0	86.0	98.0	89.0	95.0	87.0	89.0	85.0	86.0		87.0	91.0	90.0	91.8	84.0	88.0	85.0	86.0
% Exceed	27	4	31	3	28	15	0	30	7	22	7	25	3	33	0	22	0		47	0	47	0	28	0	25	0

	Friday																									
	Southbound Lane 3													Northbound Lane 3												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean	71.3	94.3	66.4	93.3	40.9	63.7	87.0	76.2	95.9	75.2	94.8	73.7	96.8	67.2		64.6			67.0		67.7		65.3		71.6	
St. Dev.	14.6	6.6	13.2	4.2	21.9	19.9	16.1	13.1	3.8	12.6	4.0	12.3	3.5	12.1		12.0			9.3		10.0		16.6		11.5	
85th Perc.	88.0	99.0	84.0	98.0	61.0	84.0	97.8	91.0	99.0	90.0	98.7	90.0	100.0	80.0		79.0			76.0		78.0		79.0		84.0	
% Exceed	30	7	21	1	17	23	2	41	9	34	3	30	15	14		12			8		12		12		24	

	Friday																									
	Southbound Fast Lane 4 N/A													Northbound Lane 4												
	0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400		0000 - 2400		0000 - 0700		0700 - 1000			1000 - 1600		1600 - 1900		1900 - 2400	
	80	100	80	100	60	80	100	80	100	80	100	80	100	80	100	80	100	60	80	100	80	100	80	100	80	100
Mean														55.1		52.7			52.7		55.8		58.0		57.2	
St. Dev.														15.9		15.6			16.5		16.1		13.9		16.3	
85th Perc.														74.0		70.0			73.0		76.0		74.0		77.0	
% Exceed														1.9		0.3			0.2		1.3		0.3		2.7	

Saturday Base Profiles

	Saturday			
	Southbound Lane 1		Northbound Lane 1	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	83.3	89.2	83.3	89.0
St. Dev.	16.1	8.4	10.0	7.6
85th Perc.	98	101	93	97
% Exceed	52	17	62	6

	Saturday			
	Southbound Lane 2		Northbound Lane 2	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	80.1	83.7	77.7	82.3
St. Dev.	14.0	9.9	10.3	7.0
85th Perc.	92	96	88	89
% Exceed	34	4	43	0

	Saturday			
	Southbound Lane 3		Northbound Lane 3	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	77.0	91.5	71.6	
St. Dev.	15.0	7.9	12.0	
85th Perc.	93	99	84	
% Exceed	43	9	23	

	Saturday			
	Southbound Lane 4 N/A		Northbound Lane 4	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean			56.5	
St. Dev.			17.2	
85th Perc.			77	
% Exceed			6	

Sunday Base Profiles

	Sunday			
	Southbound Lane 1		Northbound Lane 1	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	83.1	91.0	83.4	89.7
St. Dev.	13.1	8.2	10.2	6.5
85th Perc.	97	101	93	97
% Exceed	48	17	63	0

	Sunday			
	Southbound Lane 2		Northbound Lane 2	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	79.8	84.6	78.8	84.5
St. Dev.	13.3	9.6	9.9	5.7
85th Perc.	92	96	88	90
% Exceed	30	5	48	0

	Sunday			
	Southbound Lane 3		Northbound Lane 3	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	78.1	94.9	73.7	
St. Dev.	15.3	6.3	11.9	
85th Perc.	95	101	86	
% Exceed	43	16	28	

	Sunday			
	Southbound Lane 4 N/A		Northbound Lane 4	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean			61.1	
St. Dev.			18.6	
85th Perc.			80	
% Exceed			14	

All Days Base Profiles
Lanes 1 and 2 Combined

	Monday - Thursday			
	Southbound Lanes 1 & 2		Northbound Lanes 1 & 2	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	77.9	86.4	78.1	85.1
St. Dev.	10.1	10.9	11.6	7.7
85th Perc.	89.0	98.0	90.0	93.0
% Exceed	33	9	43	1

	Friday			
	Southbound Lanes 1 & 2		Northbound Lanes 1 & 2	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	78.7	87.0	77.7	85.3
St. Dev.	11.5	10.2	11.5	6.8
85th Perc.	90.0	98.0	89.0	92.0
% Exceed	36	10	42	1

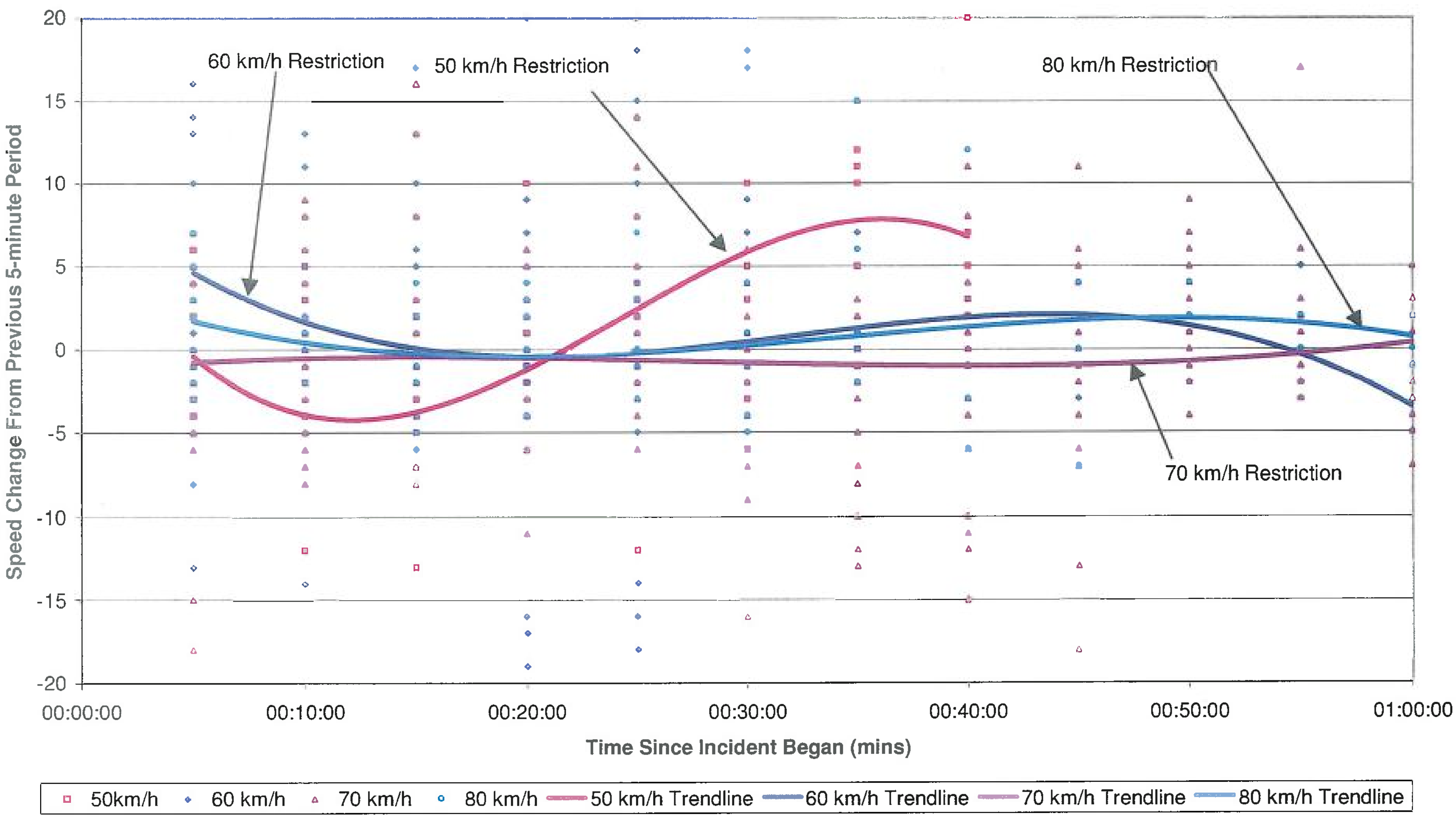
	Saturday			
	Southbound Lanes 1 & 2		Northbound Lanes 1 & 2	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	81.6	86.6	80.5	85.6
St. Dev.	15.1	9.5	10.5	8.0
85th Perc.	95.0	97.0	91.0	94.0
% Exceed	43	10	53	3

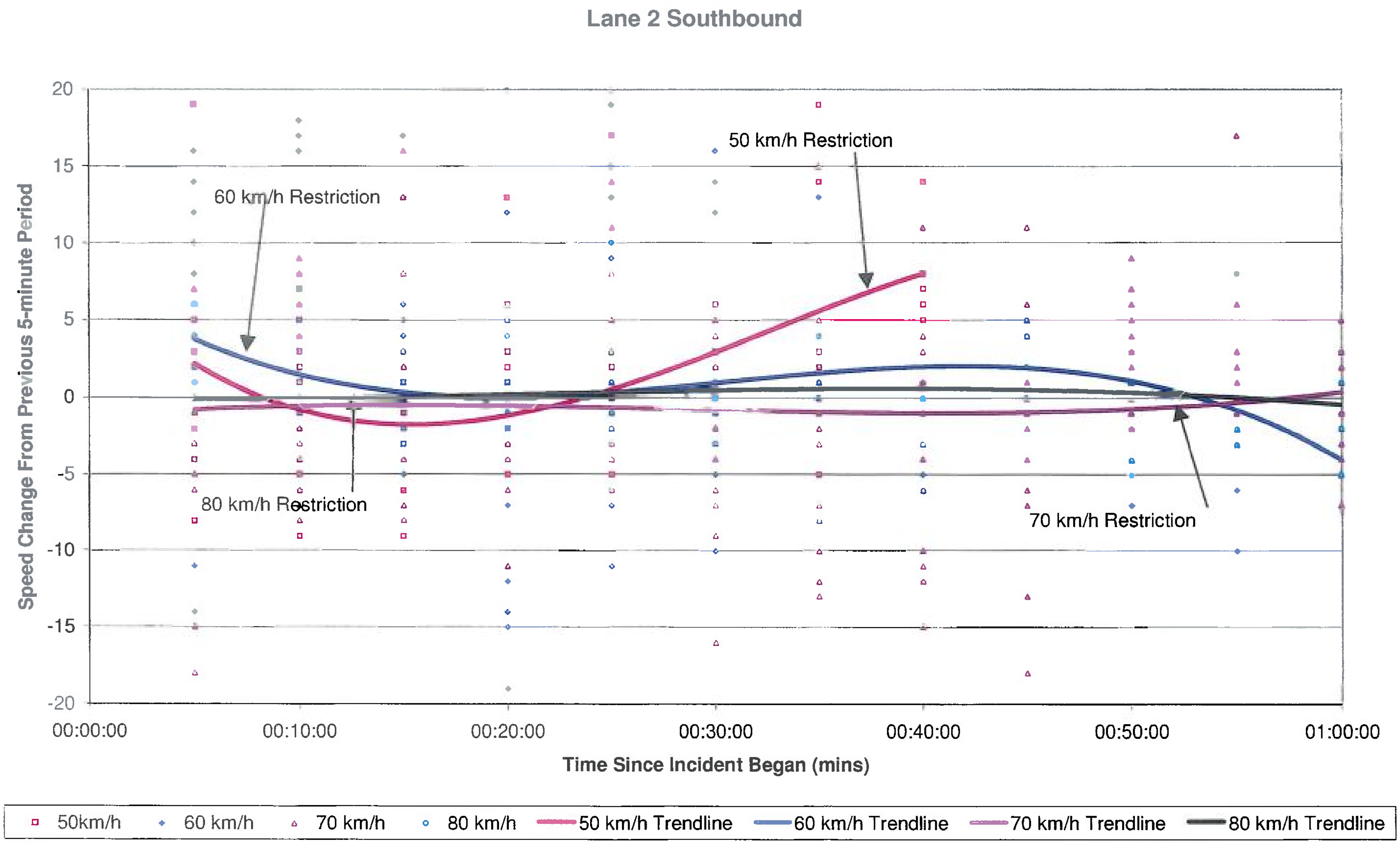
	Sunday			
	Southbound Lanes 1 & 2		Northbound Lanes 1 & 2	
	0000 - 2400		0000 - 2400	
	80	100	80	100
Mean	81.5	87.8	81.1	87.1
St. Dev.	13.3	9.5	10.3	6.6
85th Perc.	94.0	99.0	91.0	94.0
% Exceed	39	11	56	2

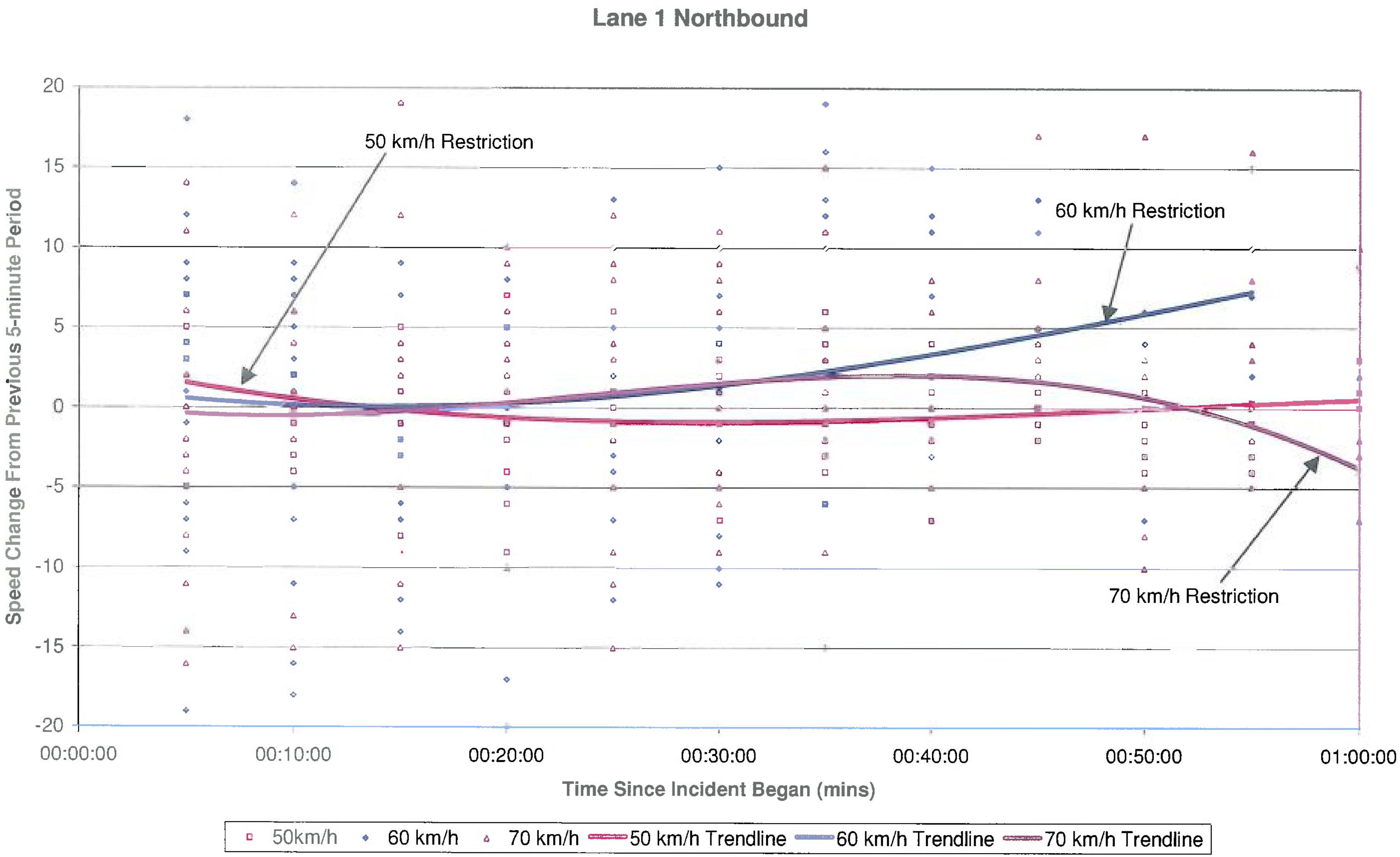
Appendix D

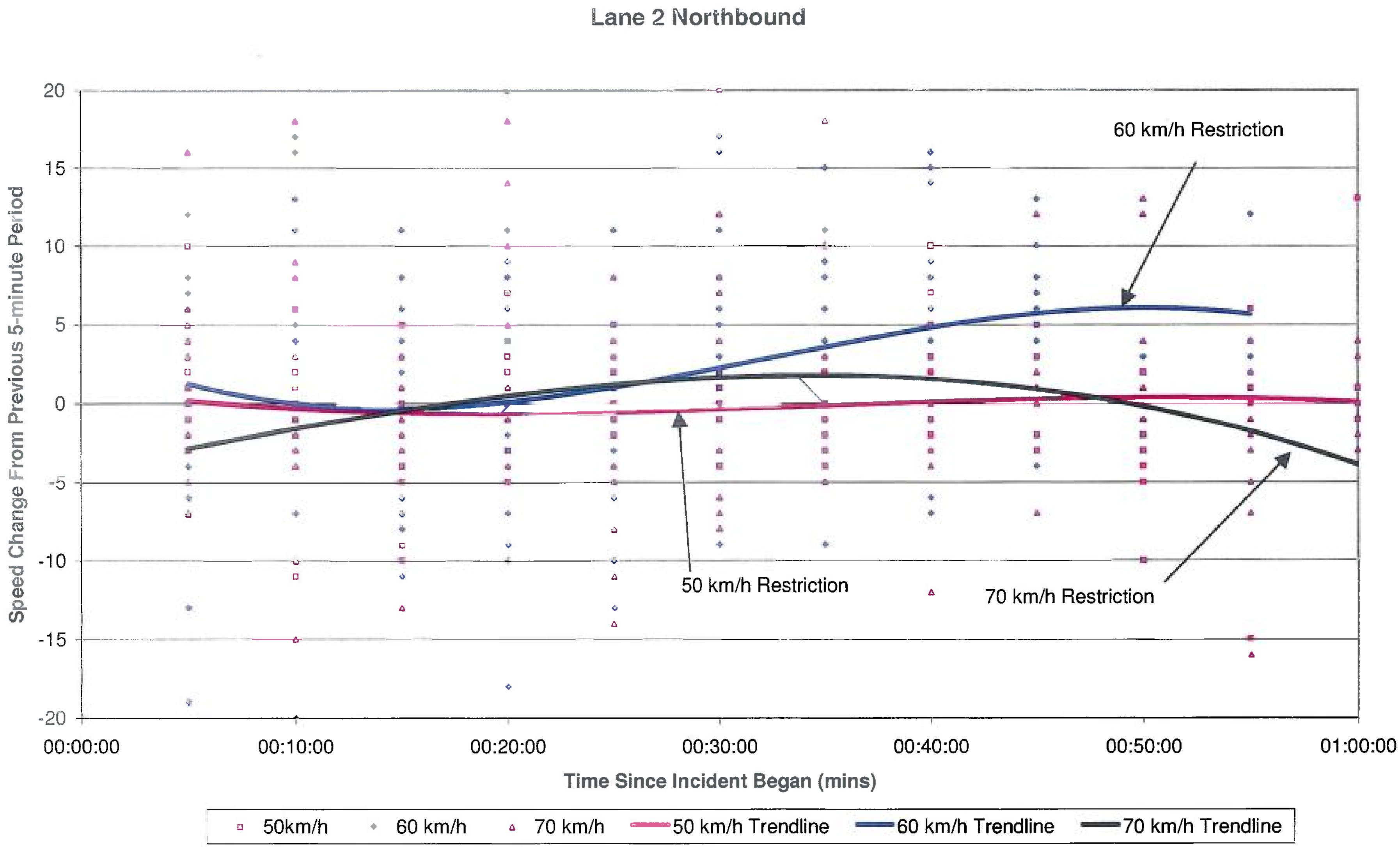
Speed Change within Individual Zones Affected by Incidents

Lane 1 Southbound




Lane 2 Southbound
Speed Change From Previous 5-minute Period
20
15
10
5
0
-5
-10
-15
-20
00:00:00
00:10:00
00:20:00
00:30:00
00:40:00
00:50:00
01:00:00
Time Since Incident Began (mins)
60 km/h Restriction
50 km/h Restriction
80 km/h Restriction
70 km/h Restriction
50km/h
60 km/h
70 km/h
80 km/h
50 km/h Trendline
60 km/h Trendline
70 km/h Trendline
80 km/h Trendline

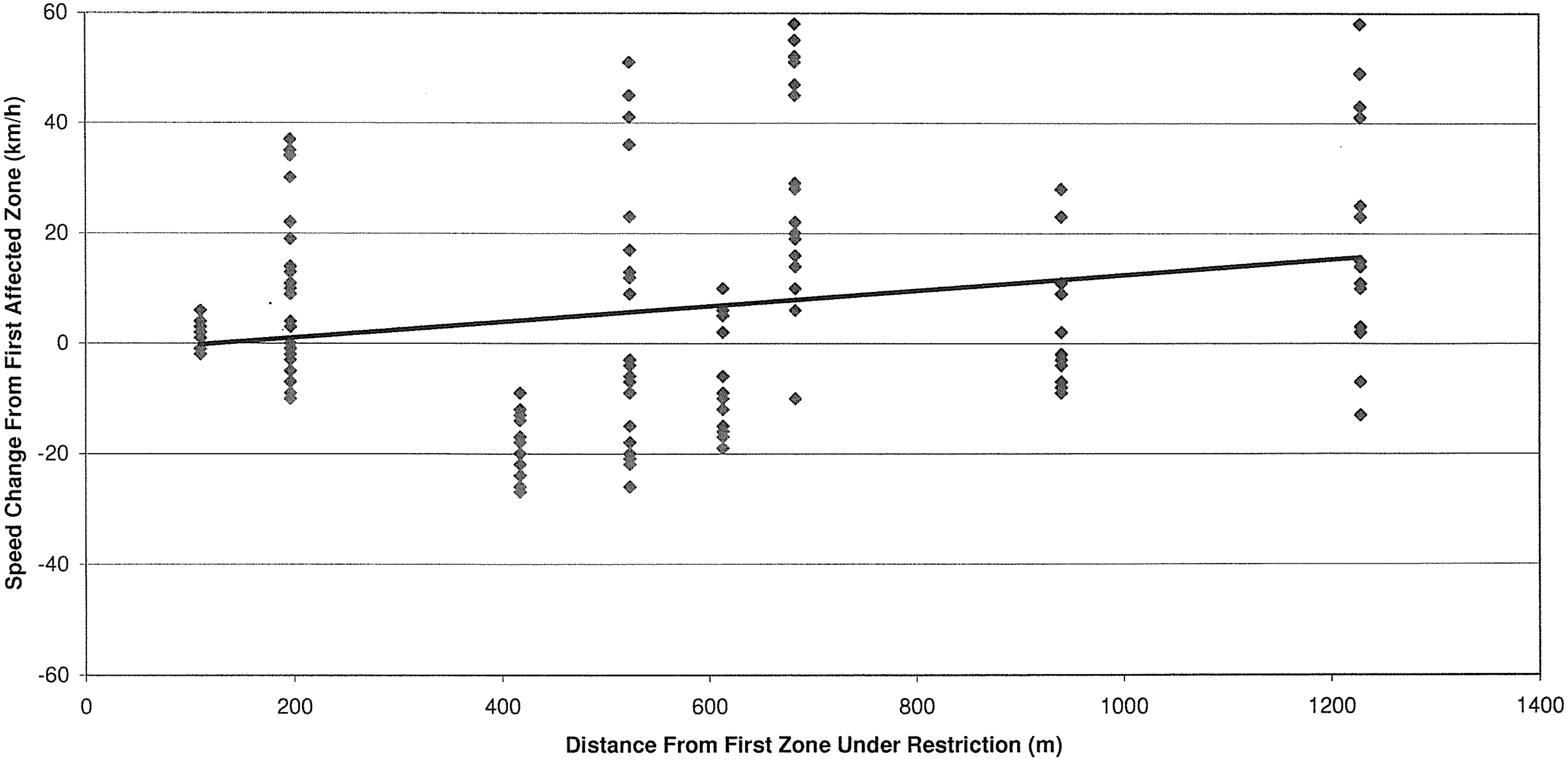

Lane 1 Northbound
50 km/h Restriction
60 km/h Restriction
70 km/h Restriction
Speed Change From Previous 5-minute Period
20
15
10
5
0
-5
-10
-15
-20
00:00:00
00:10:00
00:20:00
00:30:00
00:40:00
00:50:00
01:00:00
Time Since Incident Began (mins)
50km/h
60 km/h
70 km/h
50 km/h Trendline
60 km/h Trendline
70 km/h Trendline


Lane 2 Northbound
60 km/h Restriction
50 km/h Restriction
70 km/h Restriction
Speed Change From Previous 5-minute Period
20
15
10
5
0
-5
-10
-15
-20
00:00:00
00:10:00
00:20:00
00:30:00
00:40:00
00:50:00
01:00:00
Time Since Incident Began (mins)
50km/h
60 km/h
70 km/h
50 km/h Trendline
60 km/h Trendline
70 km/h Trendline

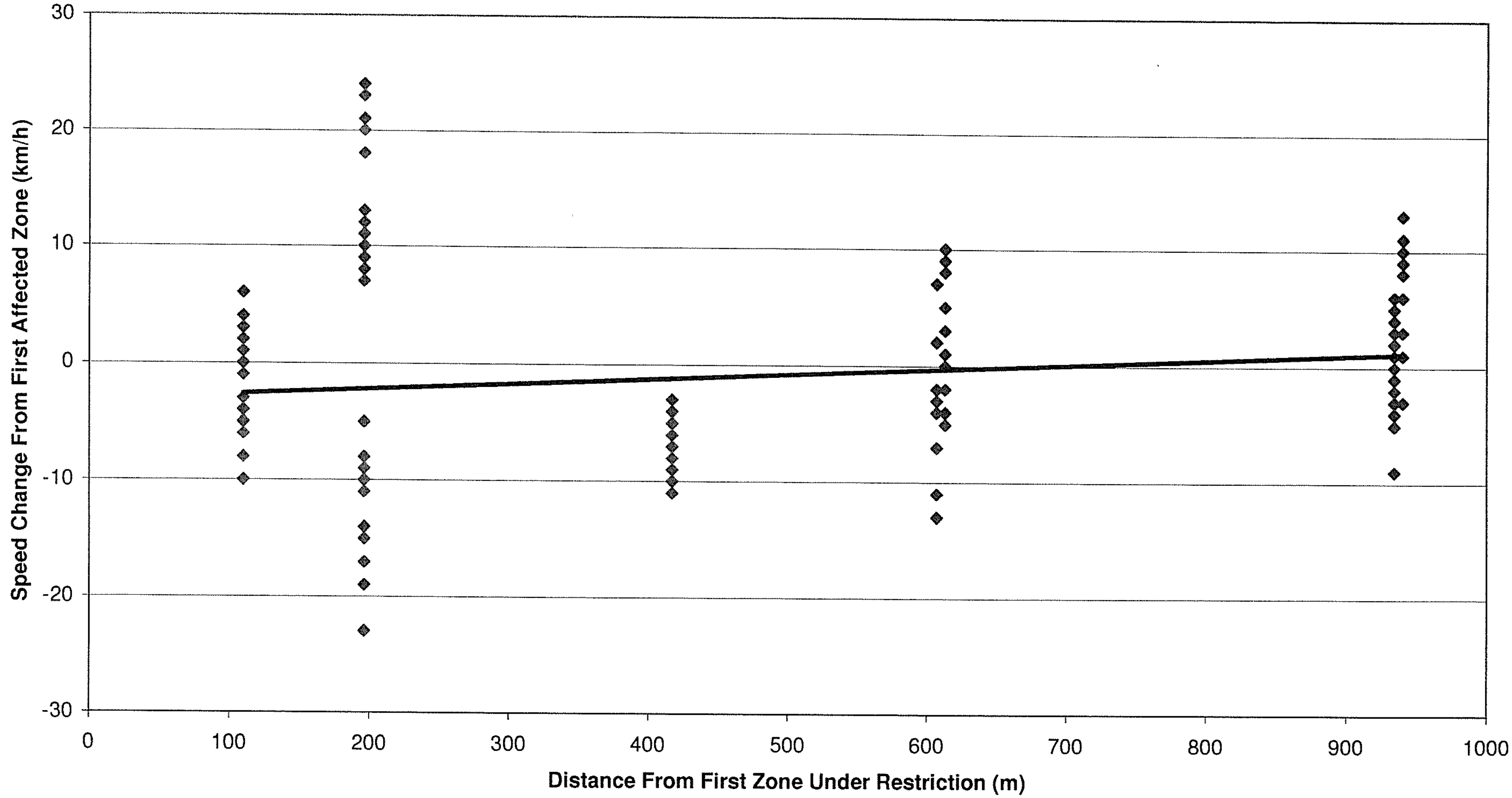
Appendix E

Longitudinal Speed Variation through the Controlled Area

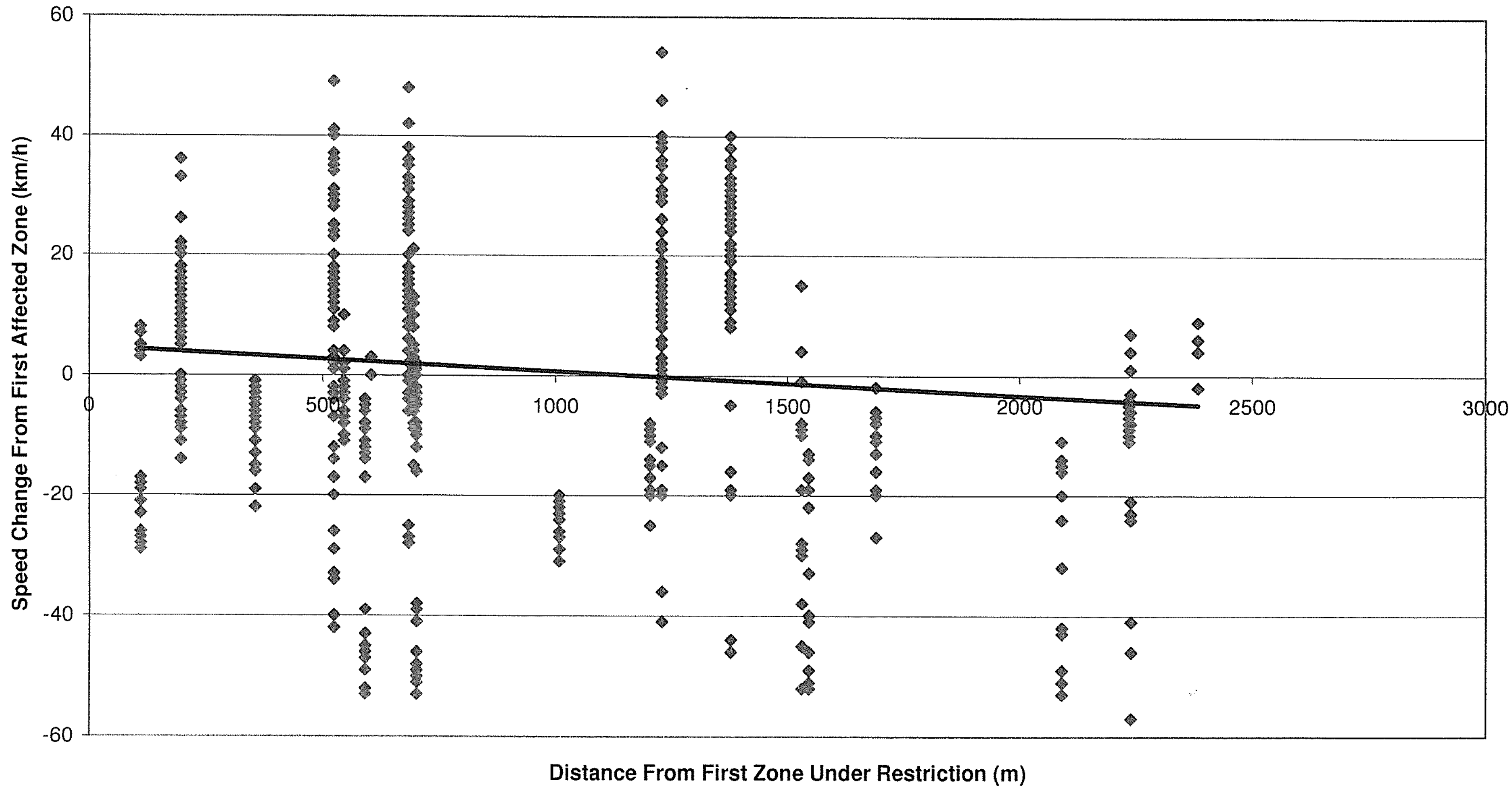
Longitudinal Speed Variability for 50 km/h Posted Speed Limit
Lane 1 & 2 Unplanned Pre-April (Northbound)

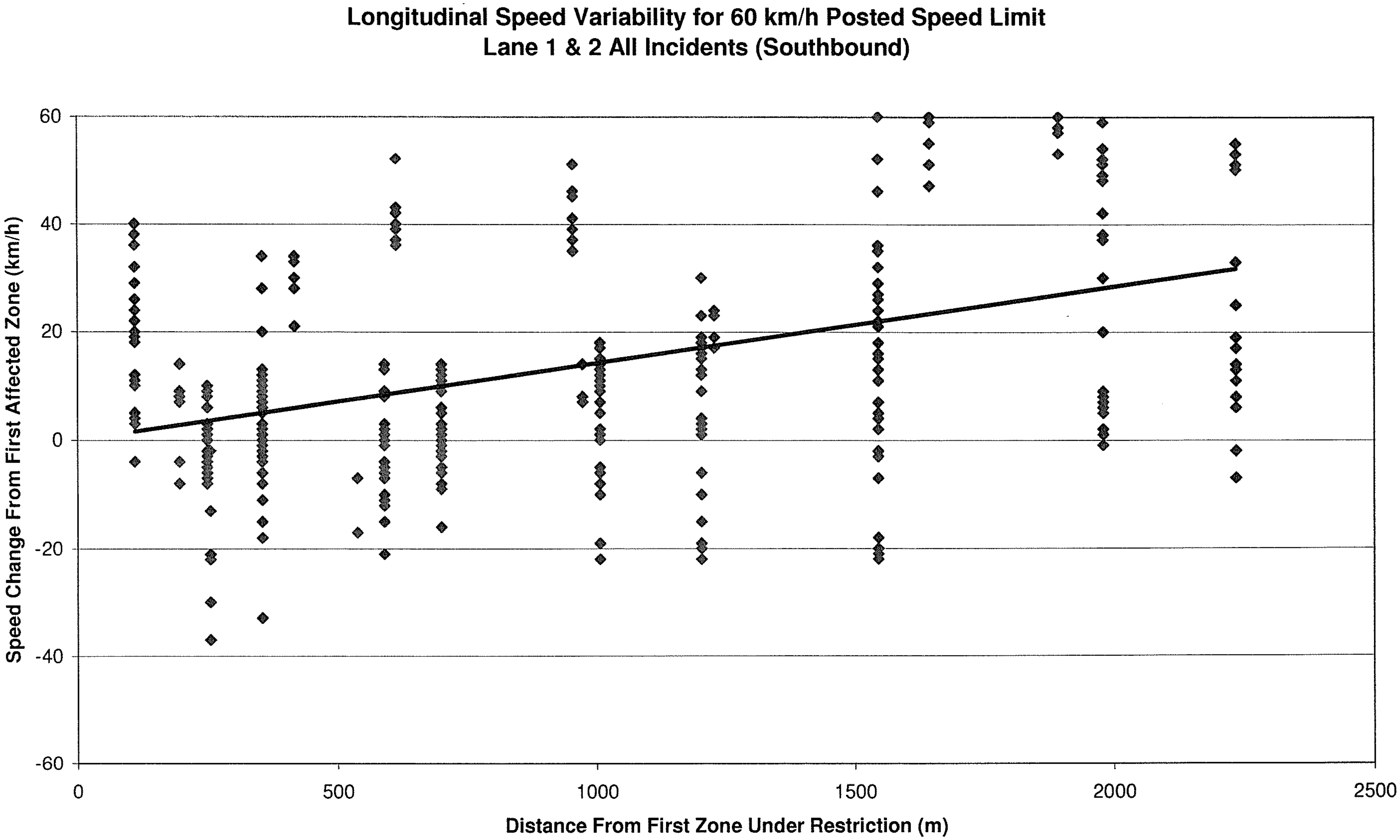


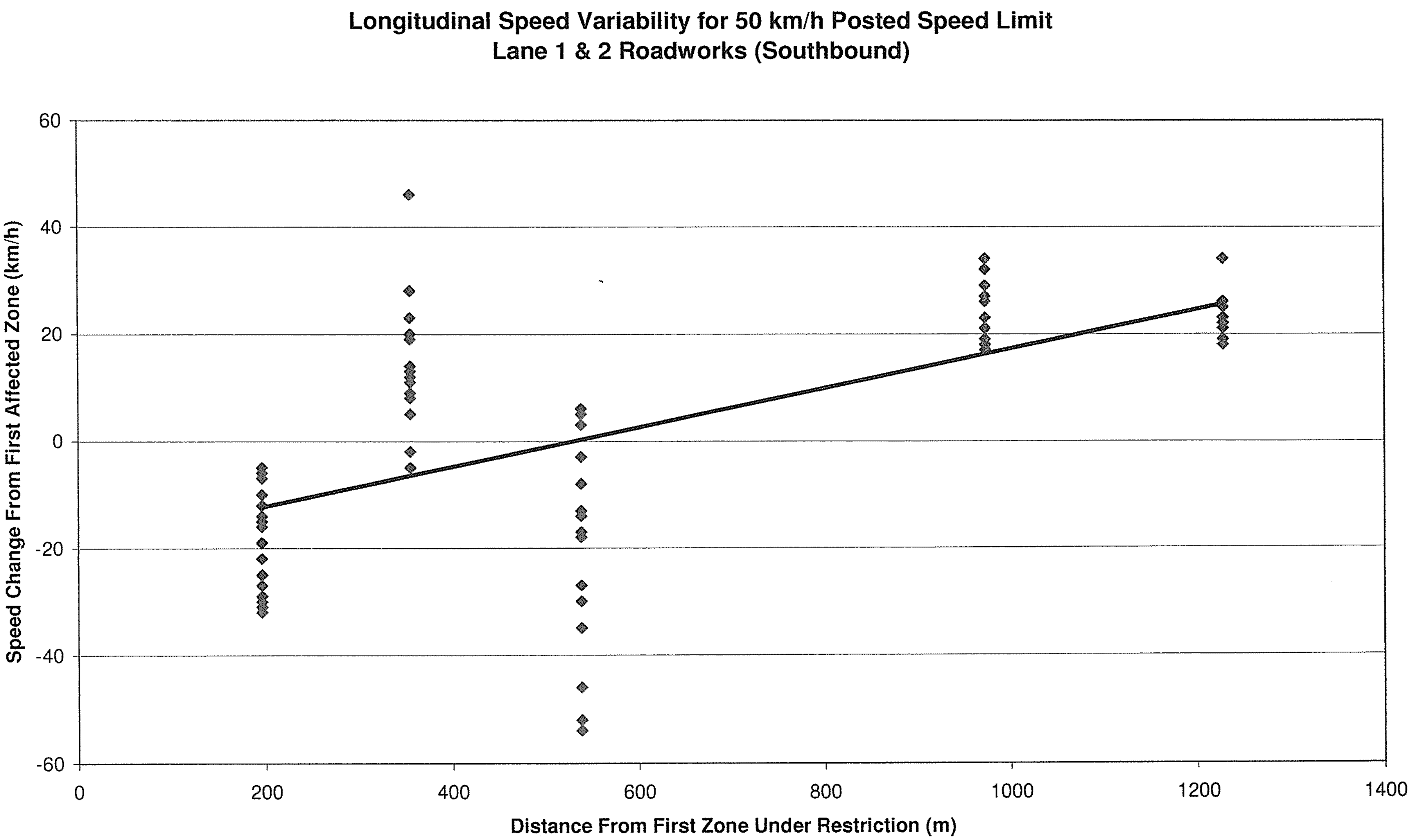
Longitudinal Speed Variability for 50 km/h Posted Speed Limit
Lane 1 & 2 Roadworks (Northbound)



Longitudinal Speed Variability for 60 km/h Posted Speed Limit
Lane 1 & 2 All Incidents (Northbound)



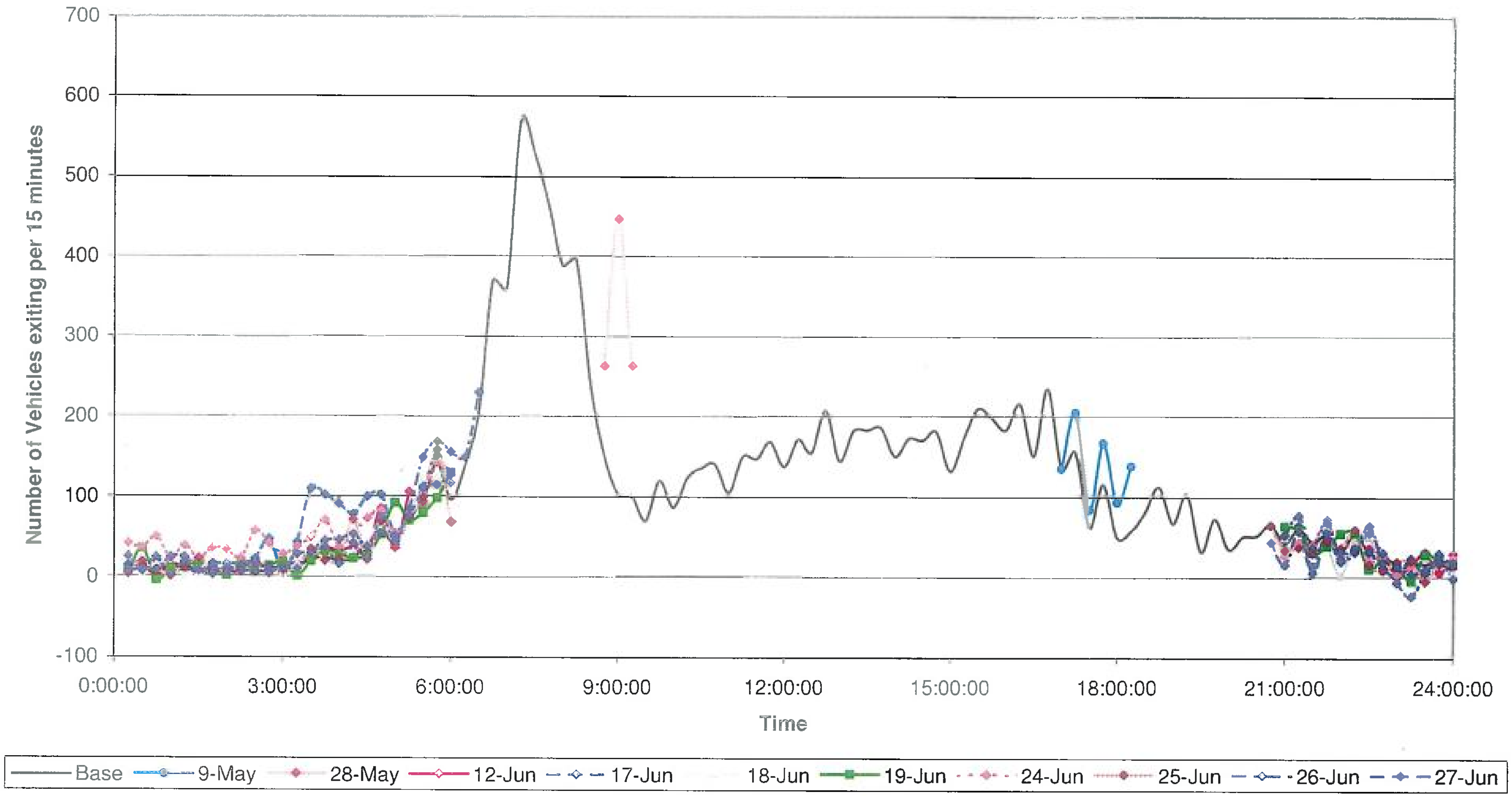

Longitudinal Speed Variability for 60 km/h Posted Speed Limit
Lane 1 & 2 All Incidents (Southbound)
Speed Change From First Affected Zone (km/h)
60
40
20
0
-20
-40
-60
0
500
1000
1500
2000
2500
Distance From First Zone Under Restriction (m)


Longitudinal Speed Variability for 50 km/h Posted Speed Limit
Lane 1 & 2 Roadworks (Southbound)
Speed Change From First Affected Zone (km/h)
60
40
20
0
-20
-40
-60
0
200
400
600
800
1000
1200
1400
Distance From First Zone Under Restriction (m)

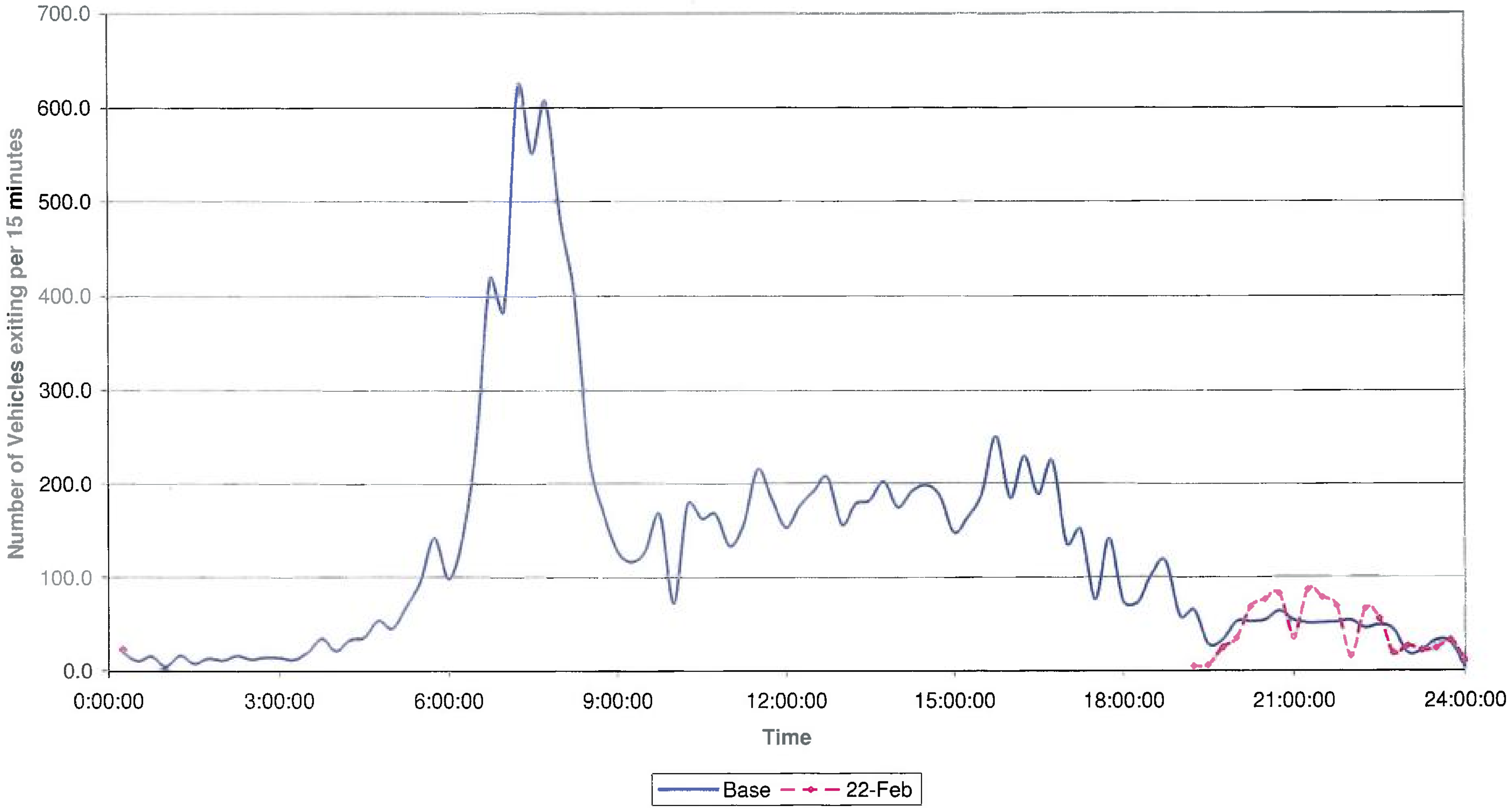
Appendix F

Hutt Off-ramp Diversionary Flow Profiles

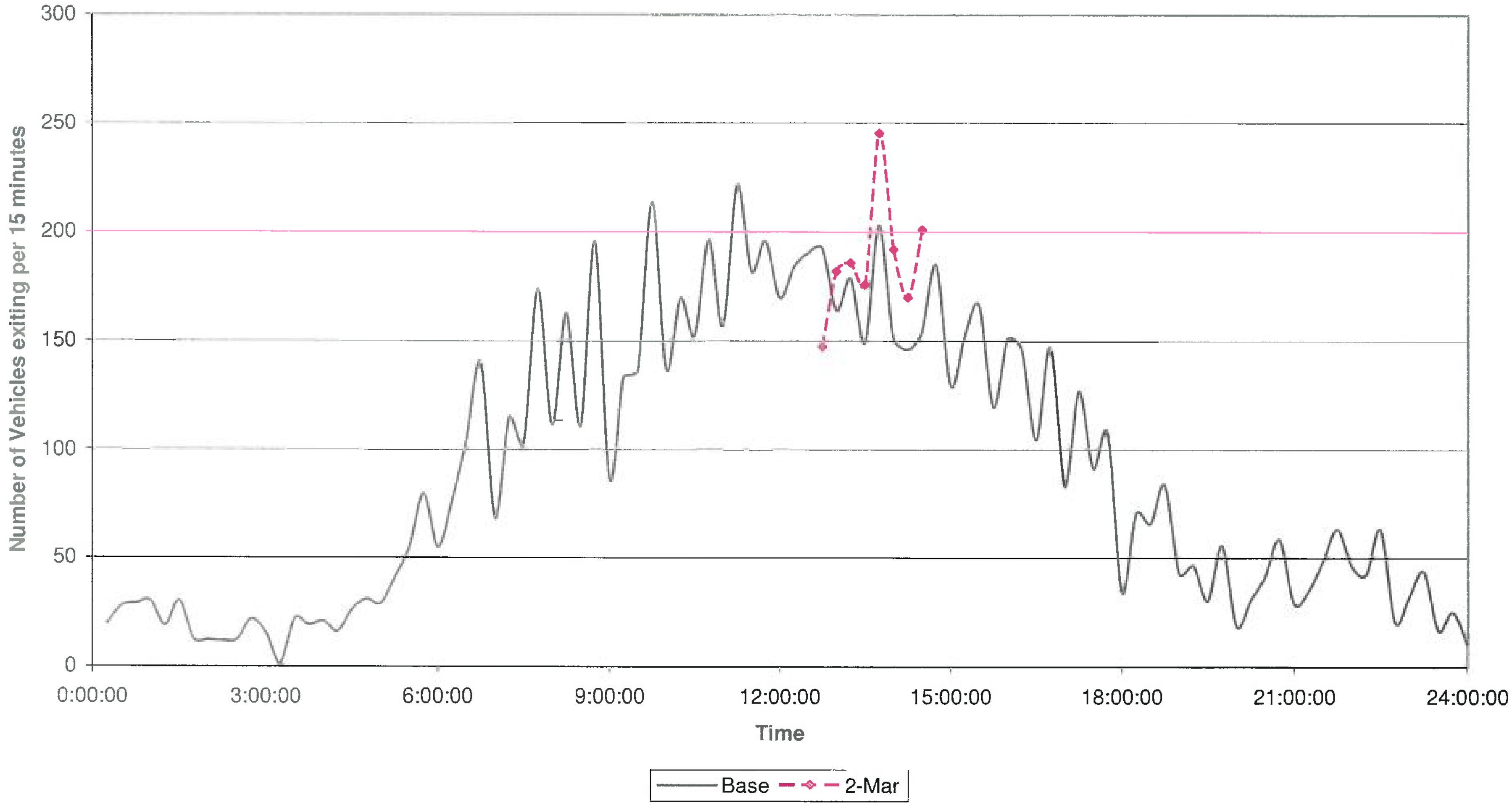
Number of Vehicles using Hutt Road as a Diversion for Incidents South of NATMS
Monday - Thursday



Number of Vehicles using Hutt Road as a Diversion for Incidents South of NATMS
Friday 22nd February 2002



Number of Vehicles using Hutt Road as a Diversion for Incidents South of NATMS
Saturday 2nd March 2002



Number of Vehicles using Hutt Road as a Diversion for Incidents South of NATMS
Sunday