Using risk analysis to assess treatments for frost and ice

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An important note for the reader

Acknowledgements

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Abbreviations and acronyms

AC	Asphaltic concrete
CMA	Calcium magnesium acetate
GN	Grip number
LWB	Locked-wheel braking
NZTA	New Zealand Transport Agency
OGPA	Open-graded porous asphalt
SS	Slurry seal

Contents

Executive summary

This study was undertaken to develop procedures for assessing the level of risk associated with treating frost and ice with either mineral grit or the anti-icing/de-icing agent calcium magnesium acetate (CMA), and to compare these levels of risk with other common road conditions, including wet and dry road surfaces. The level of risk depends on the different levels of skid resistance that occur on different surfaces at different times under different conditions, and the actual traffic levels at these times.

The research was based on:

- an on-road test programme comprising skid resistance measurements using a passenger car instrumented for locked-wheel-braking (LWB) tests
- determination of typical hourly traffic levels across a range of surfaces that are prone to frost and ice
- GripTester measurements of the variation of skid resistance with time following treatment
- assessment of the relative risks of different treatments, including the application of these at different times of the day or night.

A number of test sites were selected in the Coastal Otago area that were prone to frost and ice conditions. These test sites covered a combination of surface types and traffic levels, and included both state highway and local authority roads. Surface types included fine chipseal, coarse chipseal, open-graded porous asphalt (OGPA), asphaltic concrete and slurry seal. Skid resistance measurements were carried out over a range of conditions. These included dry surfaces (no treatment), wet conditions without CMA or grit, testing immediately following application of CMA, and testing immediately following an application of grit. Additional skid resistance measurements were also carried out using Central Laboratories' GripTester to complement the locked-wheel braking test data. These measurements looked at comparative variations between the different treatments with time after application, as well as the effects of dewfall on grit and CMA.

Conclusions

The skid resistance tests using the instrumented passenger car and the GripTester showed that:

- there was considerable variation in the stopping distances, and average and peak skid resistances across the different surfaces, treatments and road conditions
- almost all the changes in the road conditions investigated, including applications of water, CMA and mineral grit reduced the skid resistance to levels below those for a dry road on all of the different surfaces. The exception was CMA when dry
- there was considerable variation in the levels of skid resistance with all treatments, on similar road surfaces

- the reductions in skid resistance were generally greater on the smoother textured asphalt surfaces (OGPA and asphaltic concrete) than on the more textured asphalt surfaces (slurry seals) and chipseals
- CMA and grit generally performed worse on the smoother asphalt surfaces than on chipseals
- the performance of CMA with time after application was heavily dependent on environmental conditions such as temperature, humidity and wind. Good drying conditions or drainage sped up the rise in skid resistance with time after application. Cool conditions, high humidity and little wind tended to slow down this change
- when CMA was dry, it performed as well as or better than a dry road surface
- dewfall tended to reactivate the CMA, causing skid resistance to reduce, but not to the same degree as when first applied
- the performance of grit with time after application tended to improve as the grit was crushed or moved by the action of traffic
- under cool conditions with high humidity, following an application of water, CMA or mineral grit, the skid resistance might take up to six hours to rise to levels approaching those of a dry road.

Analysis of the daily variation of hourly traffic levels on the test sites indicated that:

- there was relatively little variation in the traffic levels during week days (Monday to Friday)
- there were the expected peaks in traffic levels during the morning and early evening 'rush hour' periods
- the variations in weekend daytime traffic levels were generally different from those occurring on weekdays, with traffic tending to peak more during the middle of the day.

Changes in skid resistance that can occur with a change in road conditions (application of water, CMA or grit) when combined with crash rates derived from the Cenek, Davies and Henderson (2005) crash risk model and the measured traffic levels, allowed an assessment of the expected crash risk. This showed that:

- the time at which a change in road conditions occurred, either naturally because of rain, dewfall, frost or ice, or through application of treatments for frost and ice (grit or CMA), would have a significant impact on the expected number of daily crashes
- expected crash rates were much higher for frost and ice conditions than for any other road conditions or treatments
- crash rates for all the different changes in road conditions, except for frost and ice, were much lower when these changes occurred outside the peak traffic period in the early morning and early evening. After 9pm the expected daily crash rates for all roads where the condition had changed because of water, CMA or grit were less than 5% greater than for a dry road
- treating road surfaces with grit, or with CMA, either a short period before ice or frost was anticipated, or as a routine maintenance procedure at a specific time, reduced the daily crash rate considerably compared with untreated frost or ice conditions.

- there was very little difference (1–2%) in the expected crash rate as a result of applying CMA a short period before ice or frost was anticipated, and applying it as a routine maintenance procedure at a specific time, provided that the routine application avoided the rush hour peaks
- either of these two applications of CMA was better than an application of grit, given that grit was often applied near to or after the time ice or frost had begun to form.

The research has shown that the relative risks of the common treatments for frost or ice (grit and CMA) can be assessed by determining the expected crash rates for these treatments, based on the changes they cause in skid resistance, and combining this with the variations in traffic levels. This process can also be used to assess how the timing of a particular treatment changes the level of risk.

Recommendation

It is recommended that a comparison of actual crash rates be made between those occurring on roads not treated with CMA and those occurring on roads treated with CMA or grit. This study should also consider whether there are any differences between the crash rates in urban and rural areas, and between those in areas where the environmental conditions are different, eg Central and Coastal Otago.

Abstract

The comparative effects on skid resistance of the two commonly used treatments for frost and ice on New Zealand roads, mineral grit and the anti-icing/de-icing agent calcium magnesium acetate (CMA), were examined through an on-road test programme. This involved locked-wheel braking tests on selected test sites under a variety of conditions using an instrumented car. Tests were conducted for various treatments, including dry (no treatment), wet, application of grit and application of CMA. Road surface types included fine and coarse chipseal, open-graded porous asphalt, asphaltic concrete and slurry seal. Comparisons of skid resistance were made between the different surfaces and different road surface treatments. Additional laboratory tests were conducted to assess the comparative variation of skid resistance with time following treatment. Typical traffic levels were also obtained for the test sites. These were combined with the changes in skid resistance for the different treatments at different times to provide an assessment of the relative levels of risk for road users. Some implications for managing the use of CMA and mineral grit were also examined.

1 Introduction

This research project aimed at providing roading network managers with better tools to assess the relative risks of treating frost and ice conditions with either mineral grit or the anti-icing/de-icing agent calcium magnesium acetate (CMA) at different times of the day, and under different environmental conditions. It is expected that this research will be relevant to the management of roads that are subject to frost and ice conditions, where grit and CMA can be used.

1.1 Background

Frost, ice and snow affect various parts of the New Zealand roading network with varying degrees of regularity and severity. The affected areas include coastal and central Otago, coastal and inland Canterbury and the central North Island. On roads affected by such weather conditions there is a significantly increased risk of loss-of-control skidding crashes, unless surface treatments are used to improve skid resistance.

There are two treatments commonly used in New Zealand for frost or ice conditions. These are the application of either mineral grit or the anti-icing/de-icing agent CMA. Common salt was used in New Zealand as a de-icing agent until the early 1980s when public concerns about vehicle corrosion led to its use being discontinued. Mineral grit has traditionally been used for many years by roading contractors. Anti-icing/de-icing agents commonly used overseas were considered by Transit New Zealand in a major review of options for anti-icing/de-icing of state highways carried out in 1996. CMA was considered most suitable for New Zealand conditions, given the low risk of vehicle corrosion and very minor effects on soil and groundwater. Trials of CMA as an anti-icing and de-icing agent on state highways in the central North Island and parts of the South Island, mainly coastal and central Otago was begun in 1998, and its use has expanded every year since then.

Significant reductions in the number of crashes and road closures due to ice have seen the number of sites treated with CMA increase year by year. Figure 1.1 shows how the number of winter crashes has varied through a five-year period during which CMA was introduced (Whiting 2007).

Figure 1.1 Winter crashes – Central Otago and Queenstown Lakes (Whiting 2007)

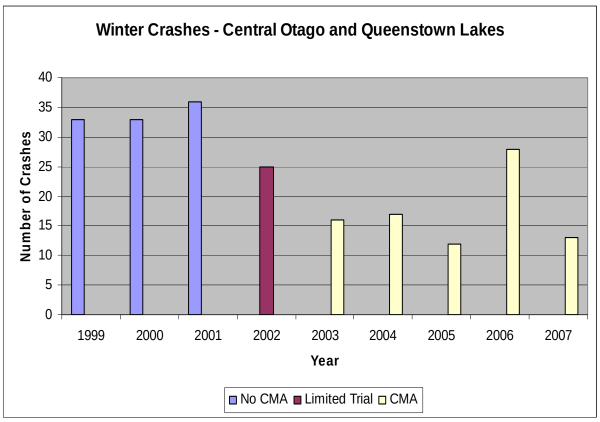


Figure 1.1 shows that, apart from a spike in winter crashes in 2006, which have been attributed to a number of reasons, including rainfall, driver error and tourist involvement, there has been a significant reduction following the introduction of CMA as a treatment for frost and ice conditions.

1.2 Need for research

Roading contractors have now had considerable experience with using mineral grit and CMA as treatments for frost and ice. However, there were still a number of issues regarding the performance and use of both these treatments that needed to be resolved. Some of these issues were highlighted in previous research carried out by Jamieson and Dravitzki (2007). The issues are listed below:

1 Little was known about the effects of mineral grit on skid resistance, both in terms of magnitude and duration, particularly on the range of New Zealand road surfaces, from low-textured slurry seals and asphaltic concrete to coarse chipseals.

2 Neither the comparative effects of mineral grit and CMA on skid resistance immediately following application, nor their performance over time, were well known. Accordingly, roading contractors were unable to choose a treatment based on its benefits for skid resistance.

3 There was a need to establish the effects of treatments at different times of the day, given different environmental conditions, particularly dewfall.

4 There was limited understanding of the exposure of traffic levels at different times of the day compared with the potential risk of lowered skid resistance from either (a) no treatment of frost or ice, (b) treatment with mineral grit, or (c) treatment with CMA.

1.3 Research objectives

The primary goal of the research programme was to develop input to ‘best practice’ procedures for assessing the level of risk associated with treating frost and ice conditions with either mineral grit or CMA. This was to be achieved through the following objectives:

1 To quantify the changes in skid resistance that occurred under different grit and CMA treatment scenarios through locked-wheel braking tests on different surfaces.

2 To determine the typical hourly traffic levels across a range of surfaces that were prone to frost and ice.

3 To combine these traffic levels with the changes in skid resistance that typically resulted from different treatments, to establish the relative levels of risk to road users.

1.4 Scope of the report

This report presents the results of a study aimed at using risk analysis to provide roading contractors with assessment tools for choosing the most appropriate type and time of treatment of impending frost and ice. The study was based primarily around an on-road test programme comprising skid resistance measurements using a passenger car instrumented for locked-wheel braking (LWB) tests. Chapter 2 discusses aspects of risk analysis, with reference to the combination of changes in skid resistance and changes in traffic levels. Chapter 3 discusses the sites selected for the on-road test programme. Chapter 4 describes the on-road test programme, including the vehicle, the instrumentation and its outputs. Chapter 5 describes a limited series of skid resistance measurements using a GripTester to provide supplementary data on selected treatment scenarios. Chapter 6 summarises results of the comparative skid resistance measurements. In chapter 7 the typical traffic levels on the test sites are presented and discussed. Analysis of the results of the research and associated findings are presented in chapter 8. Finally, conclusions and recommendations drawn from the research are given in chapter 9.

2 Risk analysis and crash risk

2.1 Background

The friction between a vehicle's tyres and the road surface is one of the critical factors influencing road safety and the likelihood of a loss-of-control crash. As environmental conditions vary the available friction levels will also vary, and drivers will need to adapt their behaviour to the changing conditions, mainly by adjusting their speed.

Driving on the road requires a high degree of concentration, and drivers respond to a combination of visual, auditory and kinaesthetic cues to control their vehicles, eg how the road looks, how it sounds, how rough it feels. This sort of information is also used by drivers to assess the friction level. Drivers may see that the road is wet, with lower friction levels, and adjust their speed accordingly. However, because there are a variety of cues and because drivers are often inconsistent and do not notice or utilise these cues, drivers' perceptions of friction can be poor. Various studies reported by Wallman and Astrom (2001) showed that while drivers do typically reduce their speed as the friction drops, this is more consistent with the visual information (a wet road, snow, ice or frost) available, rather than the actual friction levels. Therefore, it would be expected that where such poor adaptation to conditions occurs, both the risk of a crash and the crash rate would increase.

To better understand these crash risks we need to consider an approach based on 'risk analysis'. Vose (2008) describes risk analysis as 'the quantifying, either qualitatively or quantitatively, of the probability and the potential impact of some risk'. In this case we are quantifying the relative effects of different road conditions or treatments on skid resistance. To understand or analyse the risk, the skid resistance for each road condition needs to be related to:

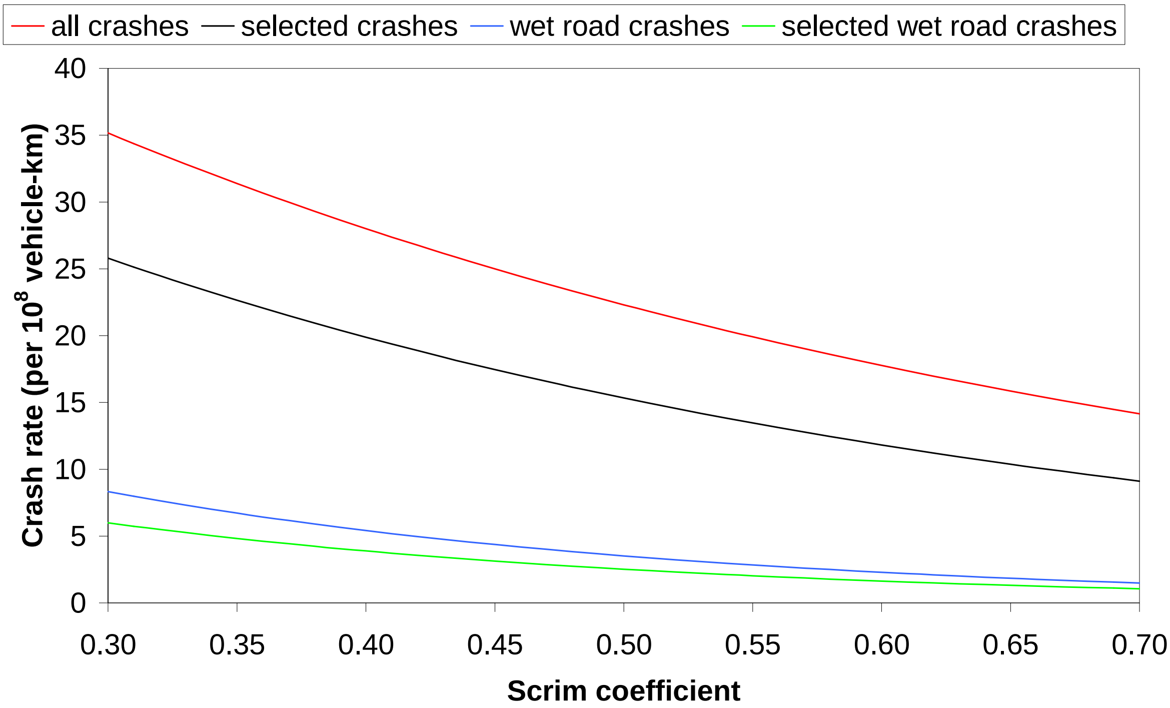
- the crash rate for that level of skid resistance
- the level of exposure to the different levels of skid resistance.

We used the locked-wheel braking tests, combined with additional GripTester measurements and information from the available literature, to help quantify the relative skid resistance levels associated with the variety of road conditions expected during winter in New Zealand. Similarly, the level of exposure to the risk of a crash could be established by determining the typical variation of the traffic level through the day. Therefore, to be able to assess the level of risk associated, for example, with ice or frost conditions compared with a dry road, the variation of the crash rate with skid resistance needed to be identified.

2.2 The effect of skid resistance on crash risk in New Zealand

The study reported by Cenek et al (2005) investigated the available New Zealand fatal and injury crash data for the years between 1997 and 2002. It linked the crash data to the road condition (including skid resistance) and geometry data. Two types of statistical analysis were performed on the data. The first analysis utilised one- and two-way tables to provide a preliminary indication of which road condition and geometry factors influenced the crash rate. The second analysis used Poisson regression modelling to identify the important contributing variables and quantify their effect on the crash rate. The resulting statistical model related the road characteristics exponentially to crash risk. Figure 2.1, which is reproduced from Cenek et al (2005), presents in graphic form, the relationship between the crash rate and skid resistance, as expressed by the SCRIM coefficient. The SCRIM coefficient is the measure used by the New Zealand Transport Agency (NZTA) to describe the road surface skid resistance measured during the annual survey of the national state highway network. Previous work by Cenek et al (2000) also showed good correlation between SCRIM coefficients and locked-wheel braking derived coefficients of friction.

Figure 2.1 The crash rate – skid resistance model (Cenek et al 2005)



Apart from the curve showing the model distribution for all crashes, figure 2.1 also shows the information for subsets of the overall crash data (selected crashes, wet road crashes and selected wet road crashes). For the purposes of this study, it has been assumed that considering all crashes is the most appropriate for comparing crash rates for the different road conditions and treatments.

3 Site selection – locked-wheel braking tests

The selection of sites for the locked-wheel braking tests was limited to the Coastal Otago area in and around Dunedin for a number of reasons. These reasons included:

- common exposure to frost and ice conditions in winter
- regular use of CMA and mineral grit to treat frost and ice conditions
- availability of a range of surface types and traffic levels
- the logistical practicalities of on-road testing.

In consultation with Graham Poxon, who was at the time the TNZ CO Hybrid Contract Manager at Downer EDI Works, a total of seven sites were selected which covered a range of surface types and traffic levels. These sites included both state highway and local authority roads, and were also chosen as being straight and flat enough so that locked-wheel braking tests could be carried out safely. The selected sites are listed in table 3.1. Photographs of the seven sites are shown in appendix A.

Table 3.1 Selected sites for comparative skid resistance measurements

Site no.	Surface type	State highway	Direction	General location	Route position	Traffic level
1	OGPA	1S	Decreasing[b]	Abbotts Creek	715/1.2	High
2	Coarse chipseal (Gr 2)	87	Increasing	South of Mosgiel	0/4.3	Low
3	Slurry seal	87	Decreasing	Outram	0/12.75	Low
4	Asphaltic concrete	DCC[a]	Eastbound	Stuart St	NA	High
5	Second coat chipseal (Gr 4)	DCC	Southbound	Three Mile Hill	NA	Low
6	Slurry seal	1S	Increasing	South Central Dunedin	706/1.2	High
7	Asphaltic concrete	DCC	Southbound	MacAndrew Rd	NA	Low

(a) DCC (Dunedin City Council controlled roads), NA – not applicable

(b) Decreasing and increasing directions are in terms of decreasing and increasing route positions

An attempt was also made to find a site surfaced with the artificial chip calcined bauxite that could be used for the study. However, this proved unsuccessful.

4 Surface friction – locked-wheel braking tests

4.1 Background

Measurement of skid resistance is not a simple matter. In any measurement of skid resistance there are often three elements involved: the road surface; the tyre and vehicle; and some form of contaminant or lubricant, such as water on a wet road, or dust, rubber, or oil. The skid resistance is dependent on all three of these and their interactions. Furthermore, each of these three elements includes a variety of factors that affect skid resistance. For example, some of these are listed in table 4.1.

Table 4.1 Factors affecting skid resistance

Road	Lubricant	Tyre
Roughness (megatexture)	Viscosity	Rubber composition
Macrotexture	Density	Tread pattern and depth
Microtexture	Film thickness	Tyre pressure
Surface temperature	Chemical structure	Rubber hardness
Specific heat capacity	Temperature	Load
Heat conductivity	Thermal conductivity	Tyre temperature
Chemistry of materials	Specific heat capacity	Thermal conductivity
	Size and shape of particles	Sliding velocity

With such a large number of possible variables interacting, it is necessary to accept a potentially large variation in skid resistance, as conditions vary. It is important to remember that any measurement of skid resistance is a snapshot in time, ie it represents the situation at the particular moment of the measurement.

There is a strong relationship between skid resistance and crash risk, and so skid resistance is very important for traffic safety and road management. Accordingly, skid resistance is routinely measured in many countries in a variety of ways. The typical approach is to try to keep as many of the influencing factors constant, usually by wetting the surface with a specific amount of water, and using a standardised tyre.

In New Zealand, at least six different skid testers are used on a reasonably routine basis. These are:

- the SCRIM+ truck that carries out the annual survey of the state highway network
- the Findlay Irvine GripTester, used by Central Laboratories and several others mostly for shorter length surveys of road or runway skid resistance
- the Norsemeter ROar, also generally used for shorter surveys
- the Dynamic Friction Tester (DFT) which uses a circular disc to make spot measurements
- the British Pendulum, also used for spot measurements

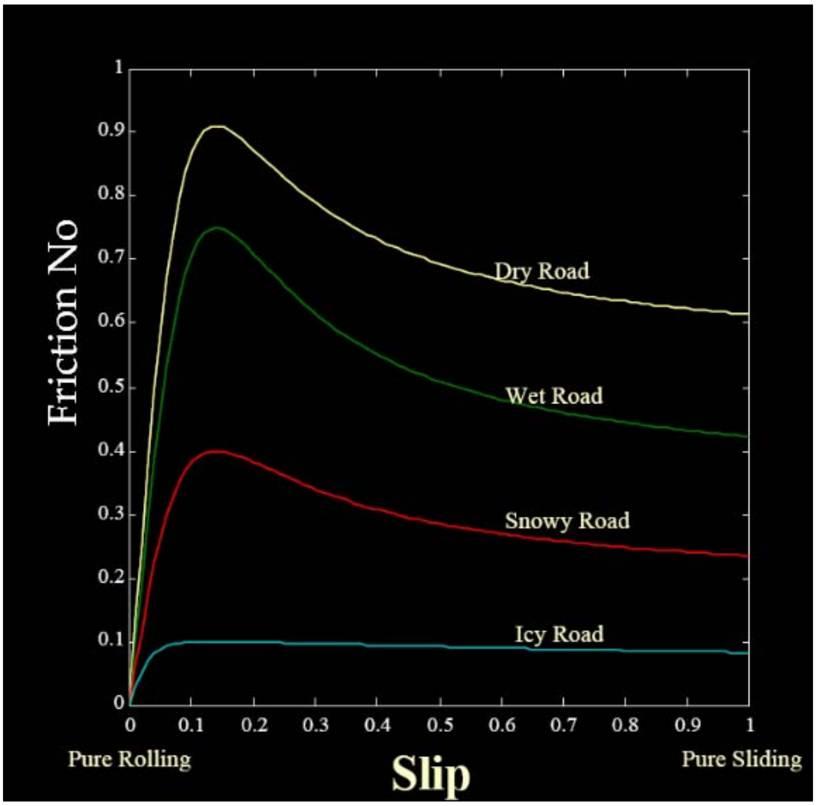
- equipping or instrumenting a vehicle to make measurements during locked-wheel braking tests. This method is routinely used by the NZ Police in crash investigations and most closely represents what happens in real-life emergency braking situations. However, its main drawback is that it is a spot measurement of skid resistance and therefore not suitable for longer network surveys. It is also relatively destructive of tyres.

4.2 Test programme – locked-wheel braking tests

4.2.1 Background

When a rolling tyre is braked from a free rolling state to a fully locked condition, the frictional forces on the tyre vary depending on the slip (the ratio between the slip speed and the operating speed). Figure 4.1 shows typical friction-slip curves for a variety of different road conditions. It can be seen that the maximum friction values occur at between 5% to 20% slip, and these are generally higher than for the fully locked condition (100% slip), except on an icy road surface. These curves are typical of what occurs during emergency, or locked-wheel, braking.

Figure 4.1 Friction-slip curve for a braking tyre (from rolling to fully locked)



4.2.2 Instrumented passenger car

The test vehicle used for the study was a Toyota Corolla (registration number BPC135) which is shown in figure 4.2. It was running on Dunlop SP Sport 200E 195/60R/15 tyres on the front and Firestone Firehawk TZ100 tyres on the rear. These were inflated to a standard pressure of 30psi. For the purposes of the testing, the anti-lock braking system (ABS) was disabled by removing the appropriate fuses. In this configuration the car's braking system defaulted to the standard configuration, with a distribution of braking pressure between the front and rear wheels that allowed the front wheels to lock, while allowing the rear wheels to continue rotating.

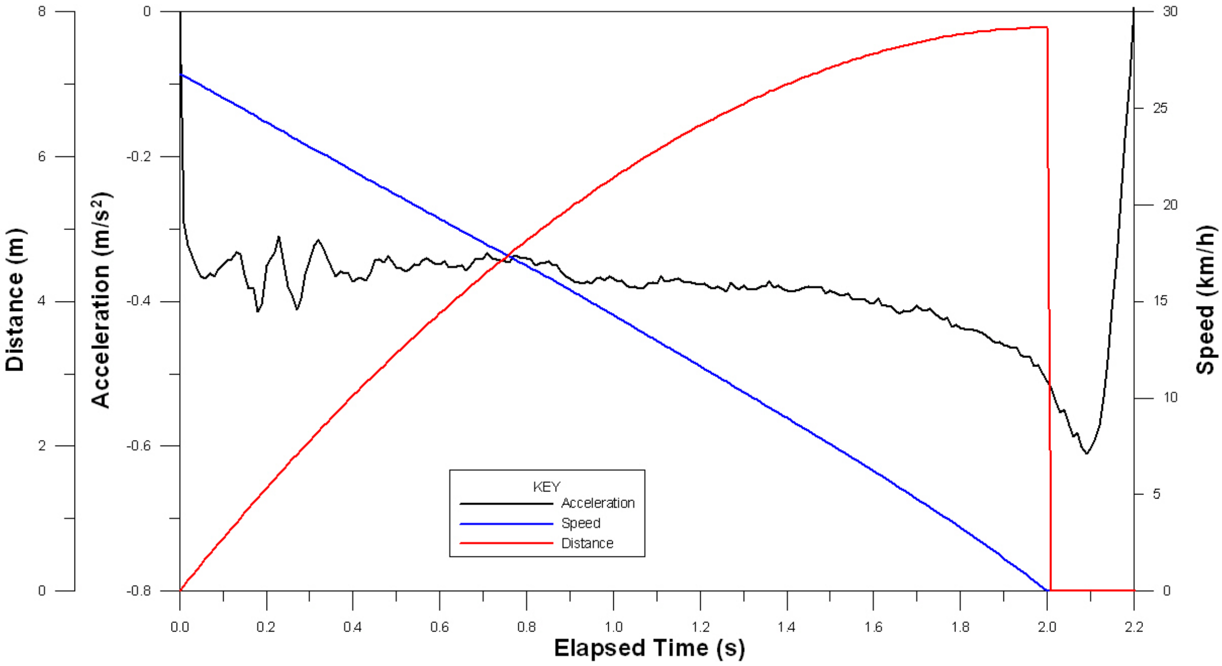
The test vehicle was instrumented with a Vericom VC3000™ Traffic Accident Computer loaned by the NZ Police. It is routinely used by the police to determine tyre-road friction values at the scenes of fatal crashes for use in crash reconstruction modelling. The Vericom unit is an accelerometer-based device that is attached to the inside of the car's windshield by suction cups.

Figure 4.2 Test vehicle – Toyota Corolla

Figure 4.3 shows the VC3000 attached to the windscreen of the test vehicle. When the 'braking' option is selected and a locked-wheel braking manoeuvre (ie an emergency stop) is initiated, a deceleration of 0.25g (1g = $9.81 m/s^2$) will trigger the VC3000 to begin recording. During the braking run, readings are taken at 100 Hz, ie every 0.01s. At the end of the run the unit displays: (1) the elapsed time, (2) the distance, (3) the adjusted distance, and (4) the skid resistance (referred to in the Vericom manual as the average G-force or drag factor). The peak G-force can also be determined from the recorded run data. Figure 4.4 shows a graph of the time history output from a typical braking run. It shows the variation of the vehicle's deceleration, speed and distance travelled, with time. Using the RS232 capability of the VC 2000, all the data from the system can be downloaded to a personal computer. The computer program provides the deceleration time history at 0.01-second intervals, which can be processed or interpreted at the user's discretion, together with the processed results of instantaneous g-force, speed and distance.

Figure 4.3 Test vehicle with the Vericom unit mounted on the windshield

Figure 4.4 Typical braking run output



4.2.3 Comparative locked-wheel braking tests

The primary aim of the test programme was to establish the difference between the skid resistance levels on different road surface conditions. The conditions expected to be of most interest were as follows:

1	dry road	no treatment
2	wet road	no additional treatment
3	CMA	immediately following application
4	CMA	following dewfall the day after application
5	grit	immediately following application
6	frost/ice	no additional treatment

Note that previous treatments leaving residual CMA or grit on the road surface were not considered, primarily because of issues with quantifying residual levels, eg the amount of grit or CMA remaining. A certain number of the above conditions could be controlled, eg the dry road, wet road, immediately post application of CMA, and immediately post application of mineral grit. However, the dewfall and frost and ice conditions relied on environmental conditions that could not be controlled. Accordingly, at each of the seven sites listed in table 3.1, a series of locked-wheel braking tests were carried out in August 2007 for those road conditions that could be controlled. The mineral grit and CMA were applied according to the standard application rates used by local roading contractors on the state highway network. These application rates were around 1 tonne/lane km for grit and 30gm/m^2 for CMA. The tests comprised locked-wheel braking measurements carried out from an initial test speed of 30km/h. A minimum of three braking tests were carried out for each road surface condition. The conditions tested were as follows:

1	dry road	no treatment
2	wet road	no additional treatment
3	CMA	immediately following application
4	CMA	a minimum of 15 minutes following application
5	grit	immediately following application

It was intended that the tests on dewfall and frost and ice conditions would be carried out if conditions and circumstances allowed. However, given the amount of information available about typical skid resistance on ice and frost, and the previous work carried out by Jamieson and Dravitzki (2007), these tests were not considered critical to the success of the project.

For each of the individual braking records, acceleration data files were recorded. The output data for each test run was also tabulated to provide a backup record. This included: (1) the elapsed time, (2) the initial vehicle speed, (3) the distance travelled, (4) the adjusted distance, and (5) the average skid resistance. The peak skid resistance, as seen in figure 4.1, could be determined by processing the recorded data files.

5 Additional skid resistance measurements

Measurements of the skid resistance under dewfall and frost and ice conditions could not be carried out during the programmed on-road testing because of environmental conditions at that time. Furthermore, for logistical reasons, longer-term variations of skid resistance with time following treatments with CMA and grit could not be carried out. Accordingly, it was decided to carry out a limited series of tests in the laboratory on selected treatments and road conditions. These tests were carried out using Central Laboratories GripTester in push mode. The tests were carried out on an asphaltic concrete surface.

5.1 GripTester – description and operation

The GripTester is a small three-wheeled skid tester that can be either pushed by hand, or towed by a test vehicle. Its principle of operation is the simultaneous measurement of load and drag on a single smooth test wheel, which slips at approximately 15% of the travel speed. The friction values can be measured at intervals ranging from 0.04m to 0.4m. The unit of friction measurement is the Grip number (GN).

Figure 5.1 shows the GripTester being used in push mode. Tests in this mode, as in tow mode, can be carried out either dry, or with water being applied at a set rate in front of the test wheel.

Figure 5.1 GripTester being used in push mode

The GripTester measuring tyre load is normally 11kg. With the standard contact area for this tyre load being 2200mm^2, this gives a tyre load/unit area of 0.005kg/mm^2. The typical tyre load for a passenger car is around 375kg, and the typical contact patch area is 10,000mm^2. This gives a tyre load/unit area for a car of around 0.0375kg/mm^2. This is much higher than the standard test configuration for the GripTester. This disparity is one of the issues that has been raised concerning comparisons of Griptester measurements with the results of locked-wheel braking tests. Accordingly, weights were used to increase the GripTester wheel load to around 0.018kg/mm^2 to assess how this increase in wheel load affected the GN output and the differences in GN between the different treatments.

5.2 GripTester – skid resistance measurements

Skid resistance tests in push mode were initially carried out for four different scenarios, these being; (a) dry, (b) wet, (c) immediately following application of grit, and (d) immediately post-CMA application. A minimum of three test runs were carried out for each surface condition.

Additional GripTester measurements of skid resistance were also carried out to investigate the following specific changes in skid resistance:

1 the level of change with time following application of water

2 the level of change with time following application of CMA

3 the variation with time following dewfall on an earlier application of CMA

4 the level of change with time following application of mineral grit

5 the skid resistance following application of mineral grit on a wet road.

Testing was carried out in conditions of low temperatures, minimal wind and high humidity, which are the most likely conditions for frost and ice to occur. Again, three test runs were carried out in quick succession to establish the inter-run variability (±0.01). Following the application of water, CMA and grit treatments, tests were repeated every 10 minutes for the next hour. The CMA was then left for another day. Dewfall was simulated by misting lightly with a water spray and the 10-minute sequence of skid testing was repeated over the next hour. The results of these tests, and the earlier locked-wheel braking tests, are analysed and discussed in the following section.

6 Results – skid resistance measurements

6.1 Results – locked-wheel braking tests

As discussed in section 4.2.3, each of the locked-wheel braking test runs was processed to provide data for the distance travelled during the braking manoeuvre, the average skid resistance and the peak skid resistance, for a common reference speed of 30km/h. The data for the test runs for each road condition and treatment was combined to provide global average values. These are listed in table 6.1.

Table 6.1 Results – locked-wheel braking tests (referenced to 30km/h)

Site no.	Surface type	Traffic level	Condition/ treatment	Distance travelled (m)	Average skid resistance	Peak skid resistance
1	OGPA	High	Dry	4.53	0.85	0.99
			Wet	5.47	0.67	0.83
			Grit	5.68	0.60	0.77
			CMA	5.99	0.60	0.75
			CMA + time	7.26	0.55	0.59
2	Coarse chipseal (Gr 2)	Low	Dry	4.87	0.74	0.91
			Wet	5.57	0.66	0.78
			Grit	5.49	0.66	0.72
			CMA	6.18	0.59	0.71
			CMA + time	5.51	0.67	0.75
3	Slurry seal	Low	Dry	4.25	0.83	1.08
			Wet	4.71	0.79	0.92
			Grit	6.02	0.58	0.73
			CMA	5.49	0.67	0.86
			CMA + time	5.55	0.65	0.83
4	Asphaltic concrete	High	Dry	5.52	0.67	0.80
			Wet	7.58	0.51	0.73
			Grit	8.12	0.43	0.53
			CMA	10.24	0.38	0.57
			CMA + time (shade)	10.88	0.35	0.53
			CMA + time (sun)	9.16	0.41	0.56
5	Second coat seal (Gr 4)	Low	Dry	5.24	0.71	0.82
			Wet	6.32	0.60	0.77

Site no.	Surface type	Traffic level	Condition/ treatment	Distance travelled (m)	Average skid resistance	Peak skid resistance
			Grit	6.20	0.59	0.68
			CMA	7.86	0.47	0.61
			CMA + time	7.14	0.51	0.60
6	Slurry seal	High	Dry	4.29	0.89	1.07
			Wet	5.24	0.75	0.78
			Grit	5.15	0.69	0.76
			CMA	5.41	0.66	0.87
			CMA + time	6.02	0.64	0.71
07	Asphaltic concrete	Low	Dry	4.44	0.87	0.98
			Wet	4.68	0.81	0.96
			Grit	9.00	0.40	0.46
			CMA	5.90	0.64	0.76
			CMA + time	6.21	0.60	0.74

Figures 6.1, 6.2 and 6.3 show bar charts of the average skidding distance, the average skid resistance and the average peak skid resistance.

Figure 6.1 Average skidding distance

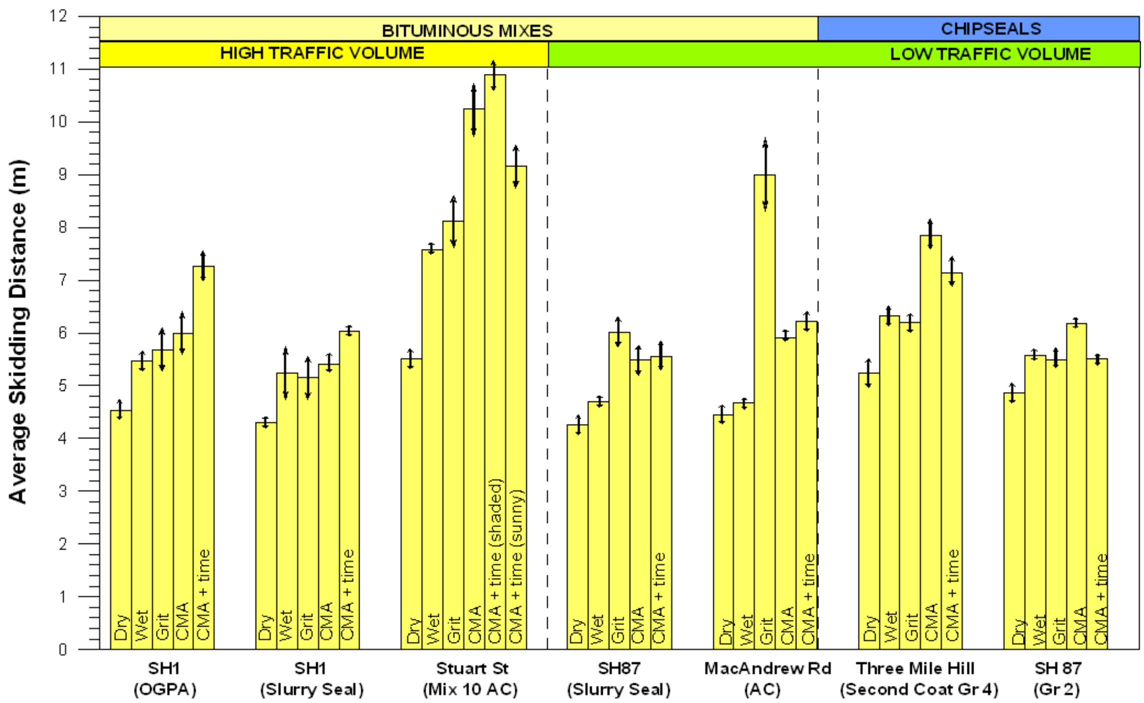


Figure 6.2 Average skid resistance

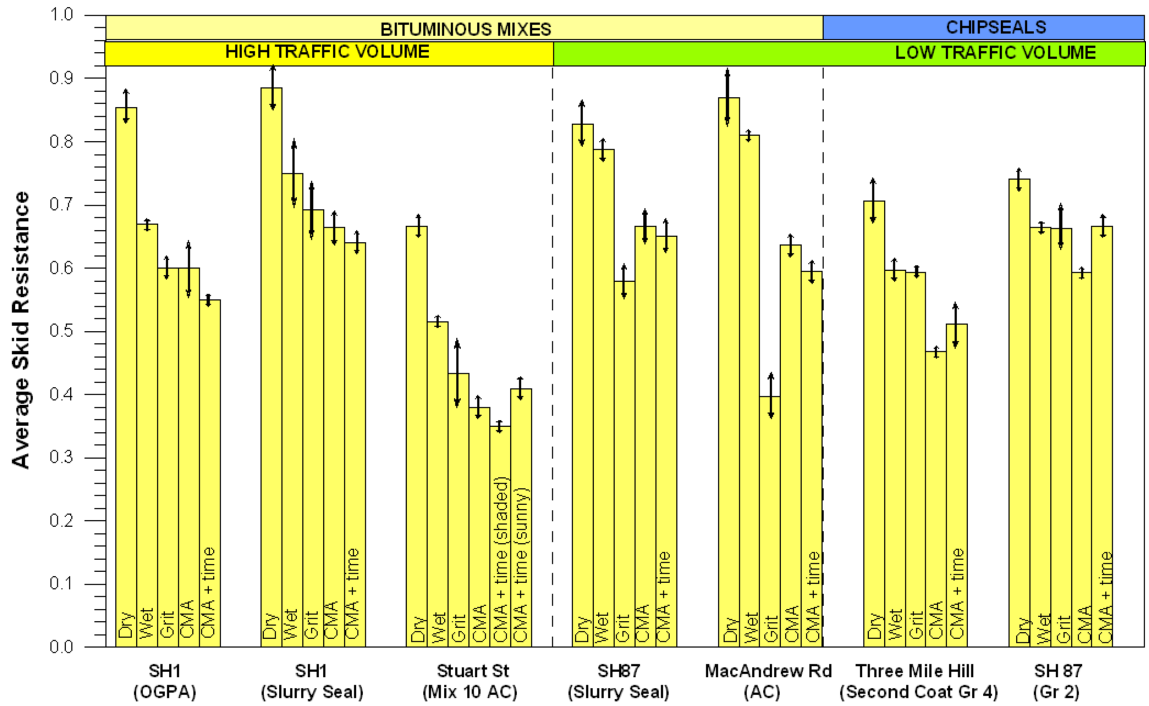
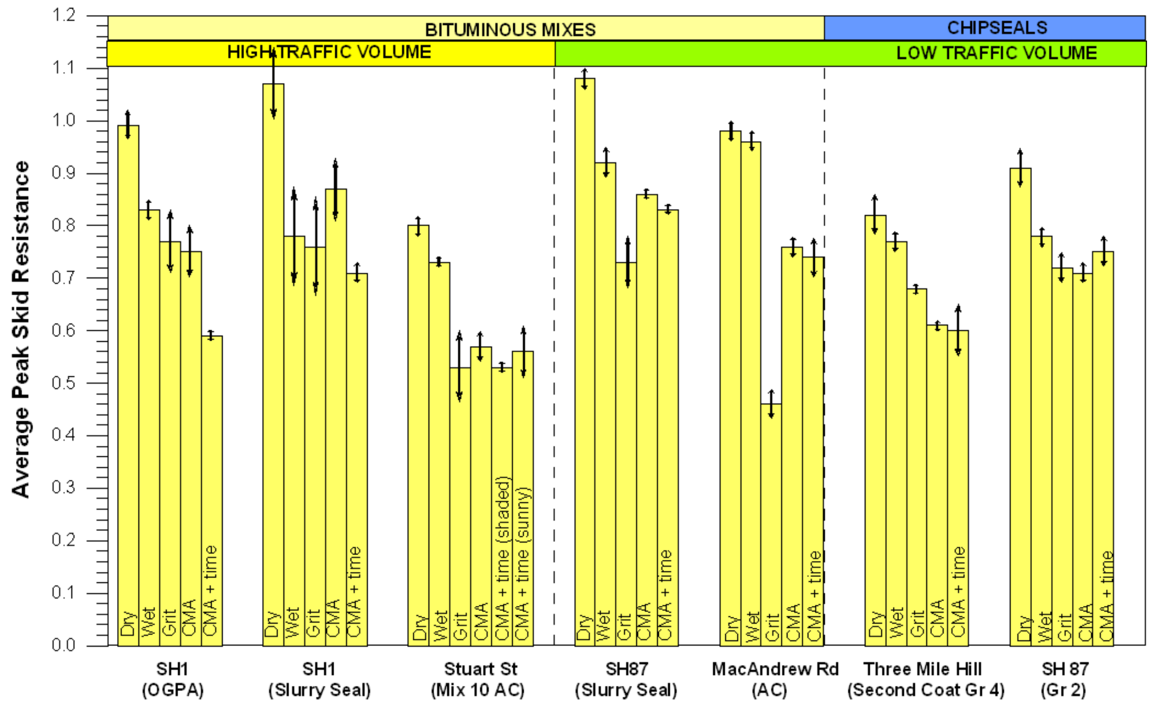


Figure 6.3 Average peak skid resistance



These figures show there is considerable variation in the stopping distances, and average and peak skid resistances, across the different surfaces and different treatments. A similar study of the effects of CMA and grit was carried out by the Dunedin City Council (Howard and Coralde 2007) under different environmental conditions, but coincidentally with the same test vehicle running on similar tyres. The average stopping distances and average skid resistance values from this study are shown in figures 6.4 and 6.5.

Figure 6.4 Average stopping distances – DCC study (Howard and Coralde)

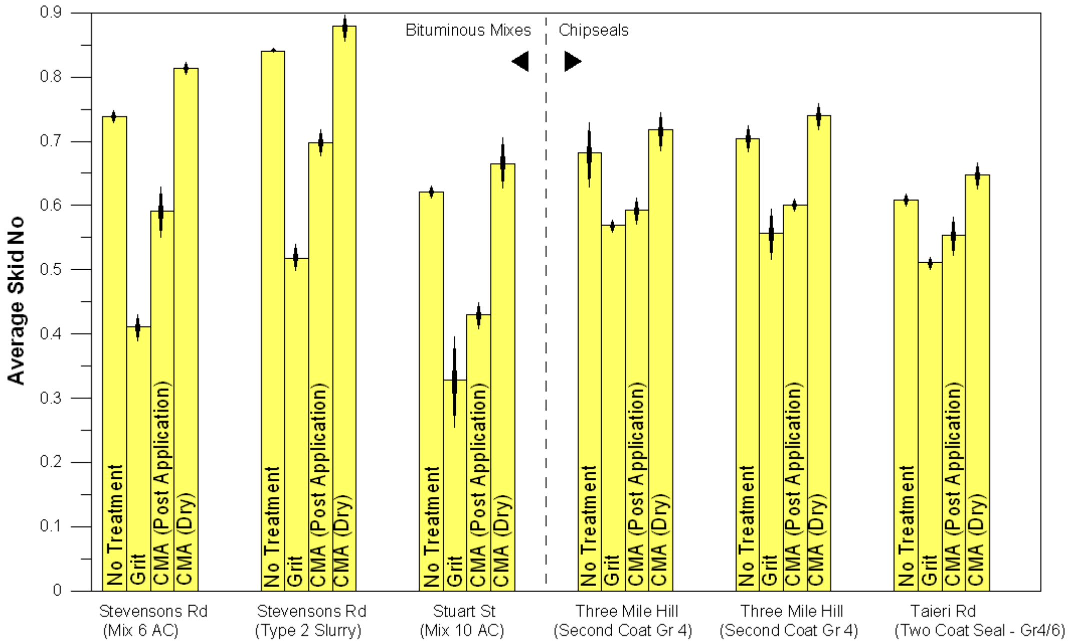
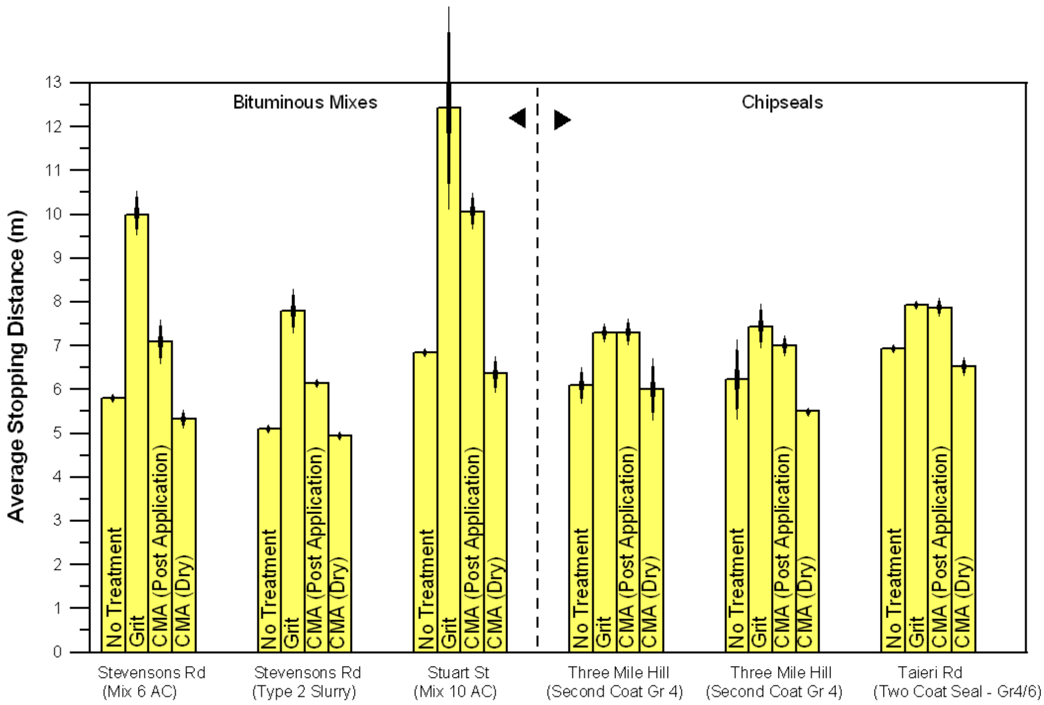


Figure 6.5 Average skid resistance – DCC study (Howard and Coralde)



Because these studies were carried out under different environmental conditions the 'starting points' for both series of tests, ie the dry road conditions, were different. To compare the effects of the treatments, the differences in the stopping distances and skid resistance were identified. These are listed in table 6.2.

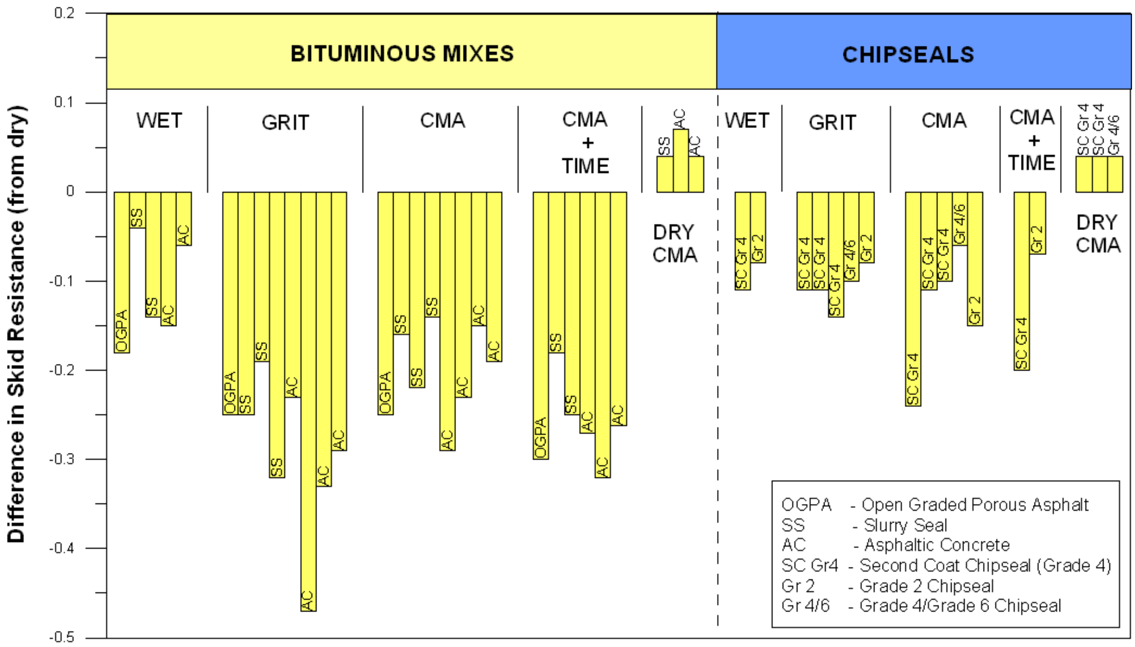
Table 6.2 Road condition – differences from dry road

Surface type	Study	Difference in stopping distance from dry road (m)					Difference in skid resistance from dry road				
		Wet	Grit	CMA	CMA +time	CMA (dry)	Wet	Grit	CMA	CMA +time	CMA (dry)
OGPA	OPUS	0.94	1.15	1.46	2.73	-	-0.18	-0.25	-0.25	-0.30	-
Gr 2 Chipseal	OPUS	0.70	0.62	1.31	0.64	-	-0.08	-0.08	-0.15	-0.07	-
Slurry seal	OPUS	0.46	1.77	1.24	1.30	-	-0.04	-0.25	-0.16	-0.18	-
	OPUS	0.94	0.86	1.11	1.73	-	-0.14	-0.19	-0.22	-0.25	-
	DCC	-	2.0	1.1		-0.9	-	-0.32	-0.14	-	0.04
AC	OPUS OPUS DCC DCC	2.06 0.24 - -	2.60 4.56 4.2 5.6	4.72 1.46 1.3 3.3	5.371 3.652 1.77 - -	- - - -0.5 -0.4	-0.15 -0.06 - -	-0.23 -0.47 -0.33 -0.29	-0.29 -0.23 -0.15 -0.19	- 0.32a - 0.26b -0.27 - -	- - - 0.07 0.04
2nd coat Gr 4 Chipseal	OPUS	1.08	0.97	2.62	1.90		-0.11	-0.11	-0.24	-0.20	-
	DCC	-	1.2	1.2	-	-0.1	-	-0.11	-0.11	-	0.04
	DCC	-	1.2	0.8	-	-0.7	-	-0.14	-0.10	-	0.04
Gr 4/6 Chipseal	DCC	-	1.0	1.0	-	-0.4	-	-0.10	-0.06	-	0.04

(a) – shaded area, (b) – sunny area

It can be seen from tables 6.3 and 6.4, and figures 6.1 through 6.5 that the treatments (water, grit and CMA) all consistently reduce skid resistance following application. However, there appears to be considerable variation across the different surface types. To assess this variation the data from table 6.2 for the difference in average skid resistance from the dry road values is presented graphically in figure 6.6.

Figure 6.6 Changes in skid resistance with treatment compared to a dry road



The following general trends can be seen in the data shown in figure 6.6:

- There is considerable variation between the performance of all treatments across the different surfaces and also across similar surfaces.
- Following application, all the treatments cause skid resistance to reduce to levels below that of a dry road.
- These reductions are generally greater on the smoother-textured asphalt surfaces than on the more textured chipseals.
- Over all the different surfaces, grit and CMA perform worst on the smoother asphalt surfaces.
- The performance of CMA with time following application appears to be variable, sometimes it is worse and sometimes better than immediately after application.
- When CMA is dry it performs the same or better than a dry road.

To try to simplify comparisons between the treatments, the data shown in figure 6.6 was combined to give an average value for each treatment on asphalt and chipseal surfaces. The results are given in table 6.3.

Table 6.3 Road condition – average differences from dry road () = ☚ data range

Treatment	Asphalt surfaces	Chipseal surfaces
Wet	-0.11 (0.07)	-0.10 (0.02)
Grit	-0.29 (0.18)	-0.11 (0.03)
CMA	-0.20 (0.09)	-0.13 (0.11)
CMA + time	-0.26 (0.08)	-0.14 (0.07)
Dry CMA	05 (0.02)	+0.04 (0.00)

This shows that the average decrease on chipseal surfaces is generally the same for all the treatments. However, this is not the case on asphalt surfaces.

6.2 Results – additional skid resistance measurements – GripTester

As discussed in section 5.2, additional skid resistance measurements were carried out with a GripTester operating in push mode. These were carried out to investigate the following specific changes in skid resistance:

1 the level of change with time following application of water

2 the level of change with time following application of CMA

3 the variation with time following dewfall on an earlier application of CMA

4 the skid resistance following application of mineral grit on a wet road.

6.2.1 Grip number (GN) – differences from dry road

The results of the measurements immediately following application of the different treatments are listed in table 6.4. Also listed are the corresponding average results derived from the locked-wheel braking tests.

Table 6.4: GripTester data – immediately following application

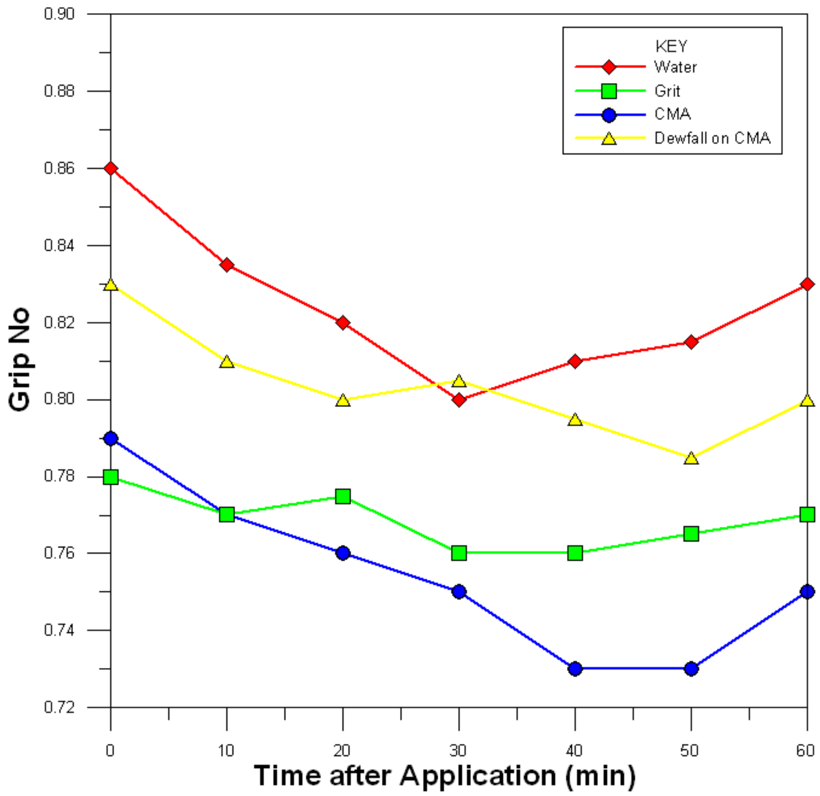
Treatment	Average GN	Difference from dry road (GN)	Average skid resistance (LWB)	Difference from dry road asphalts (LWB)
None (dry road)	1.00	NA	0.79	NA
Wet	0.86	-0.14	0.68	-0.11
Grit	0.78	-0.22	0.57	-0.29
CMA	0.79	-0.21	0.57	-0.20

This shows that while the absolute GN values do not agree with the average locked-wheel braking values, the differences from a dry road condition are comparable. It suggests that the GripTester data can be used for comparing differences in skid resistance.

6.2.2 Variation of skid resistance (GN) with time

The variation of skid resistance with time following either wetting of the road through rain or dewfall, or application of mineral grit or CMA is a complex issue. Changes in skid resistance with time can be affected by environmental conditions, such as temperature, humidity, or wind, or by traffic. As described earlier, testing of the variation with time using the GripTester was carried out in conditions of low temperatures, minimal wind and high humidity. The results for the variation over the first hour following application of water, CMA and grit, and the hour following dewfall on CMA after 24 hours is shown in figure 6.6.

Figure 6.6 Variation in skid resistance over one hour after application



This shows that following application, all treatments fell further below the dry road values for periods ranging up to around 50 minutes. It also shows that even after one hour the levels of skid resistance had not risen again to the levels immediately following application. The variation of grit on a wet road is not shown in figure 6.6, as measurements showed that there was little variation from those values for grit on a dry surface. Extrapolating the trends in the data would suggest that, for the conditions under which this testing was carried out, the skid resistance would rise to approximately the dry road values in around three hours for water, CMA and dewfall on CMA scenarios, and around six hours for the mineral grit. It is likely that in colder conditions, the water, CMA and CMA on dewfall scenarios may take as long as six hours to achieve near dry road values. The rises in skid resistance are attributed to a combination of drying and drainage for the liquid applications (water, CMA and dewfall), and to grit being crushed or moved by wheel action.

6.3 Skid resistance on frost and ice

There have been numerous studies of skid resistance on frost and ice. One of the most comprehensive of these was reported by Martin and Schaefer (1996). This presents skid resistance data for a wide variety of ice, frost and snow conditions. These show that typical skid resistance values for frost and ice conditions that might be expected in New Zealand range from around 0.15 to 0.25.

7 Traffic levels

7.1 Traffic data extraction

For each of the sites listed in table 3.1, traffic data was obtained from either Transit NZ (now the NZTA), or the Dunedin City Council. Hourly traffic data for the week closest to the date of the locked-wheel braking tests was extracted for the closest traffic data sites. Plots of the daily data for each of the sites have been included in appendix B. Figure 7.1 shows plots of the daily data for one of the higher and one of the lower trafficked sites. Figure 7.2 shows plots of the average of the weekday data for these two sites. These have been plotted on identical axes to illustrate the differences between these sites.

Figure 7.1 Daily traffic levels – high traffic and low traffic sites

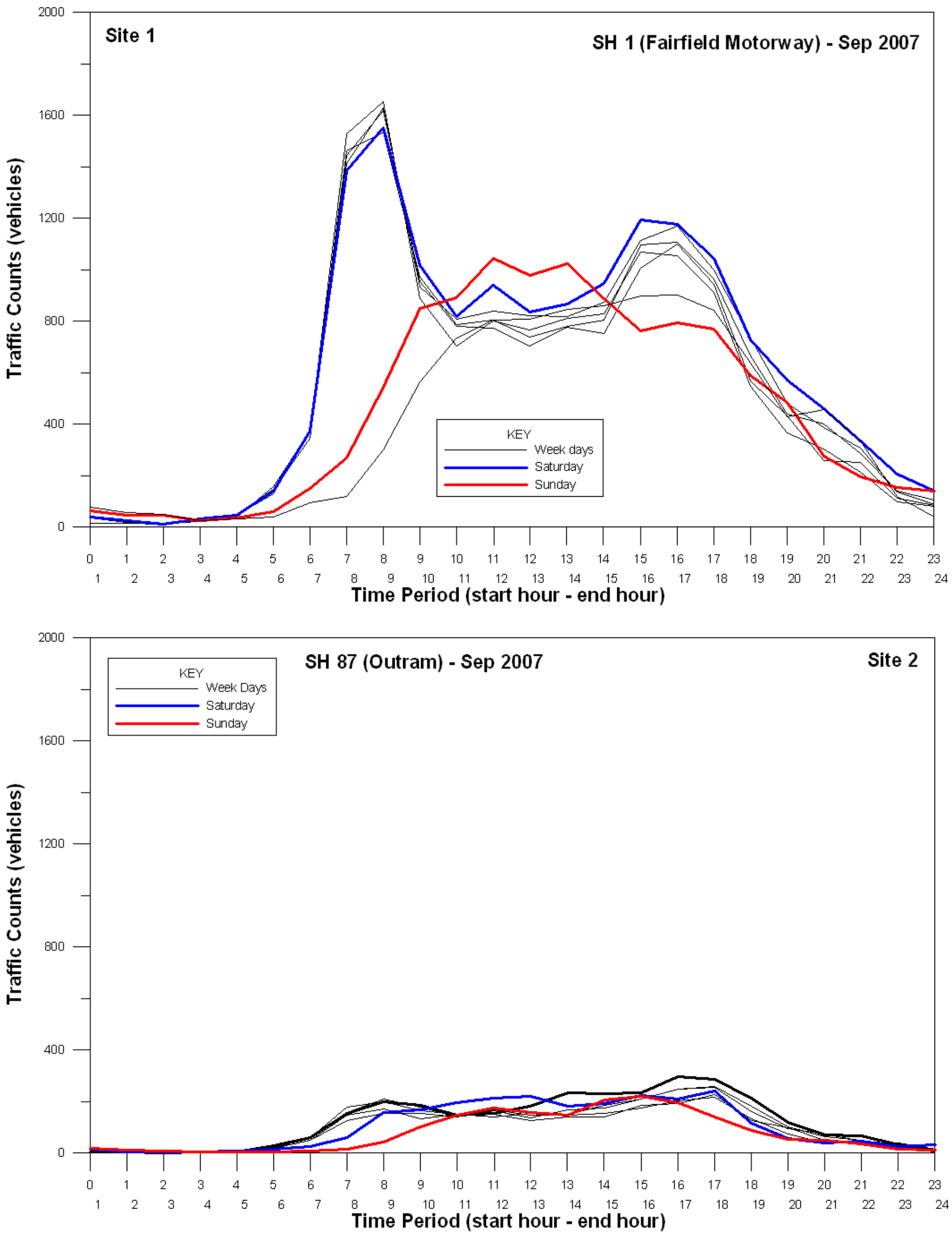
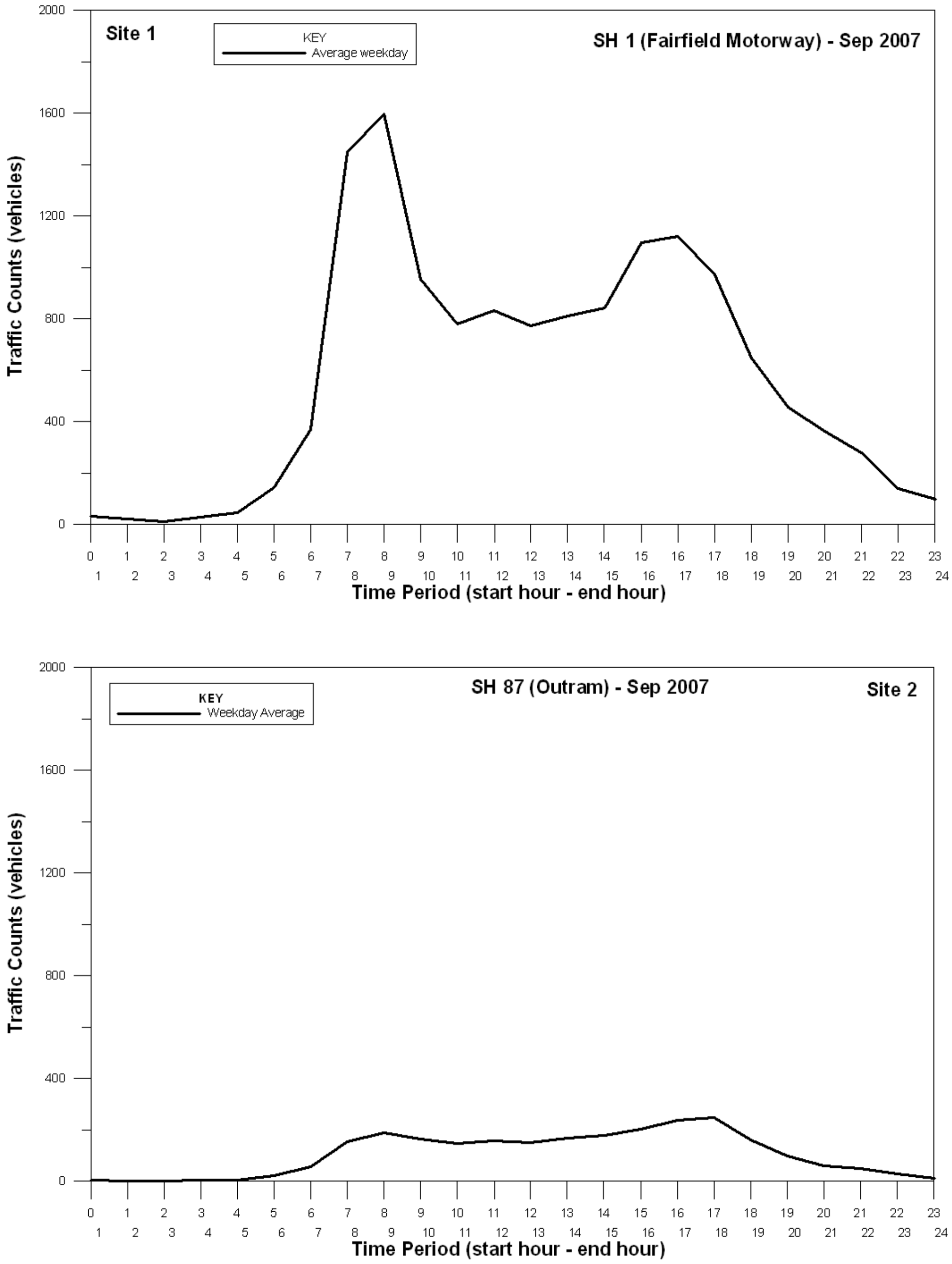


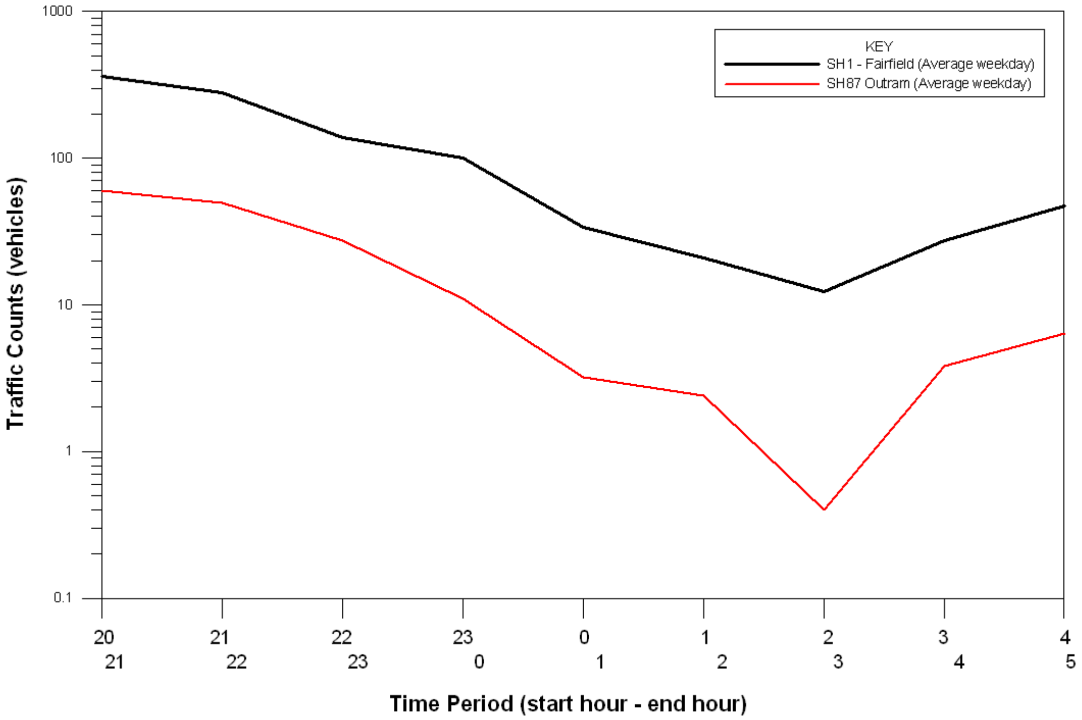
Figure 7.2 Average weekday traffic – high and low traffic sites



These figures illustrate the large differences that can occur on the roading network, either state highways, or local authority roads.

Given that most applications of mineral grit or CMA occur during the night-time hours, mostly from around 4am to 8am for grit, and mostly from around midnight to 7am for CMA, figure 7.3 shows more detail for the hours from 8pm (2000hrs) to 5am (0500hrs). This has been plotted on a logarithmic scale so that the differences are more evident.

Figure 7.3 Traffic from 8pm to 5am (high traffic site and low traffic site)



This shows that during this period of the night, the high traffic site consistently has around 10 times more vehicles than the low traffic site.

8 Data analysis

8.1 Crash risk and measured skid resistance

We have measured the skid resistance for a variety of road surface conditions, including the most common treatments for frost and ice used in New Zealand, ie mineral grit and CMA. We can relate these to a crash rate according to the models derived by Cenek et al (2005). These crash rates are summarised in table 8.1 for the average, maximum and minimum skid resistance levels. The average skid resistance values for ice and frost have been based on measured values published in the available literature. The skid resistance values for dewfall on CMA have been based on the differences identified from the GripTester measurements.

Table 8.1 Calculated crash rate for different levels of skid resistance

Treatment	Average skid resistance	Crash rate (per 10^8 vehicle-km)	Minimum skid resistance	Crash rate (per 10^8 vehicle-km)	Maximum skid resistance	Crash rate (per 10^8 vehicle-km)
None	0.79	11.8	0.67	15.1	0.88	9.5
Wet	0.68	15.2	0.51	21.8	0.81	11.3
Grit	0.57	19.0	0.40	28.0	0.69	14.5
CMA	0.57	19.0	0.38	29.2	0.67	15.0
CMA+time	0.55	20.0	0.35	31.3	0.67	15.0
CMA+dewfall	0.61	17.5	0.60	17.8	0.63	16.7
Ice/frost	0.20	42.7	0.15	46.0	0.25	39.0

Evaluations of the expected crash rate at the sites where skid resistance measurements were made, or sites where the skid resistance and traffic levels are known, can now be done by multiplying the measured traffic levels by the calculated crash rates for the different skid resistance levels established for the different road conditions. By knowing the variation in traffic levels through the day, the effects of any change in conditions, or any treatment, at any particular time can be established.

To assess the effects of different treatments at different times a number of different scenarios were considered. These were chosen primarily to illustrate the differences between treatments most likely to occur between mid to late afternoon and the early morning. It was assumed that the skid resistance changes from the dry road condition in each case lasted about six hours. This is a conservative length of time according to the plots shown in figure 6.6, except perhaps for frost and ice conditions, but allows for the small decrease in skid resistance identified for the hour immediately after application.

The selected scenarios were as follows:

1 Rain wetting the road at 3pm
2 Rain wetting the road at 6pm
3 Rain wetting the road at 9pm
4 Rain wetting the road at 12am

5 Grit applied at 3pm

6 Grit applied at 6pm
7 Grit applied at 9pm
8 Grit applied at 12am

9 CMA applied at 3pm
10 CMA applied at 6pm
11 CMA applied at 9pm
12 CMA applied at 12am

13 CMA applied, with dewfall at 3pm on the following day
14 CMA applied, with dewfall at 6pm on the following day
15 CMA applied, with dewfall at 9pm on the following day
16 CMA applied, with dewfall at 12am on the following day

17 Ice/frost formation at 3pm
18 Ice/frost formation at 6pm
19 Ice/frost formation at 9pm
20 Ice/frost formation at 12am

Plots of the variation of crash rate with time were prepared for one of the most highly trafficked sites (SH1 – Fairfield) and one of the lowest trafficked sites (SH87 – Outram), for each of these 20 scenarios. These have been reproduced in Appendix C. Rather than presenting all the plots here; figures 8.1 to 8.4 illustrate the differences between an icy road condition and the application of CMA at the corresponding time for the most highly trafficked site (SH1 – Fairfield).

Figure 8.1 Ice and CMA at 3pm

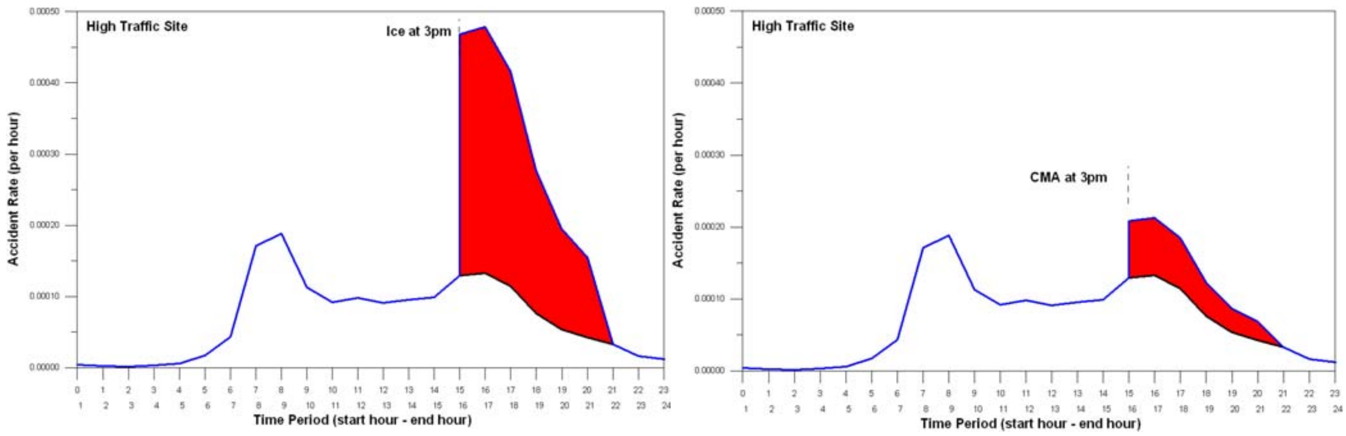


Figure 8.2 Ice and CMA at 6pm

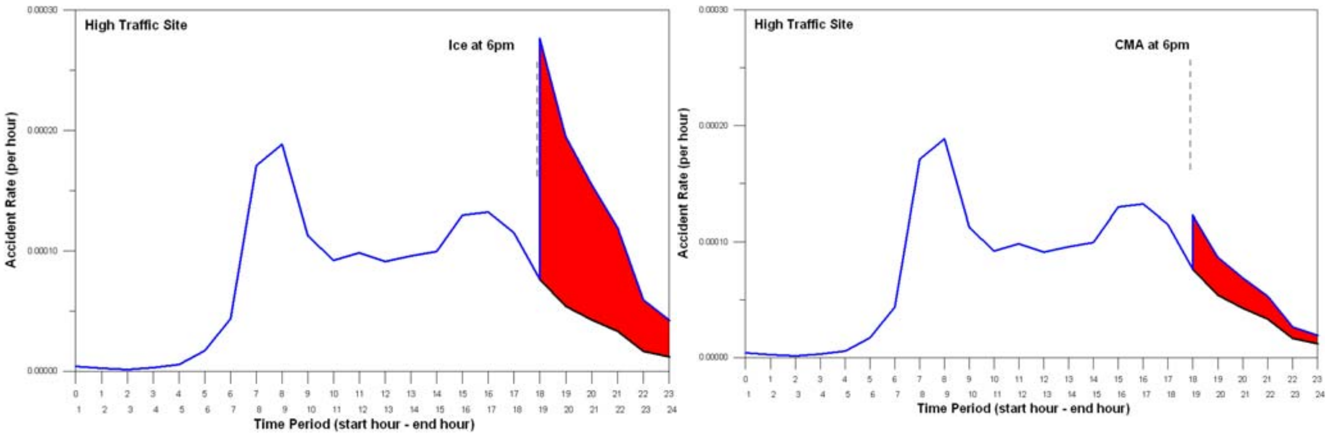


Figure 8.3 Ice and CMA at 9pm

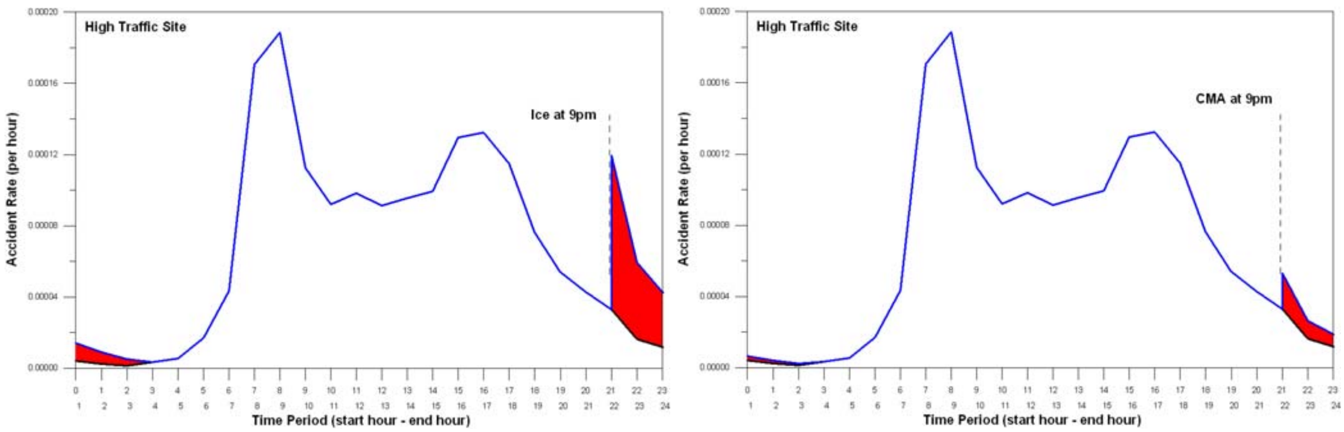
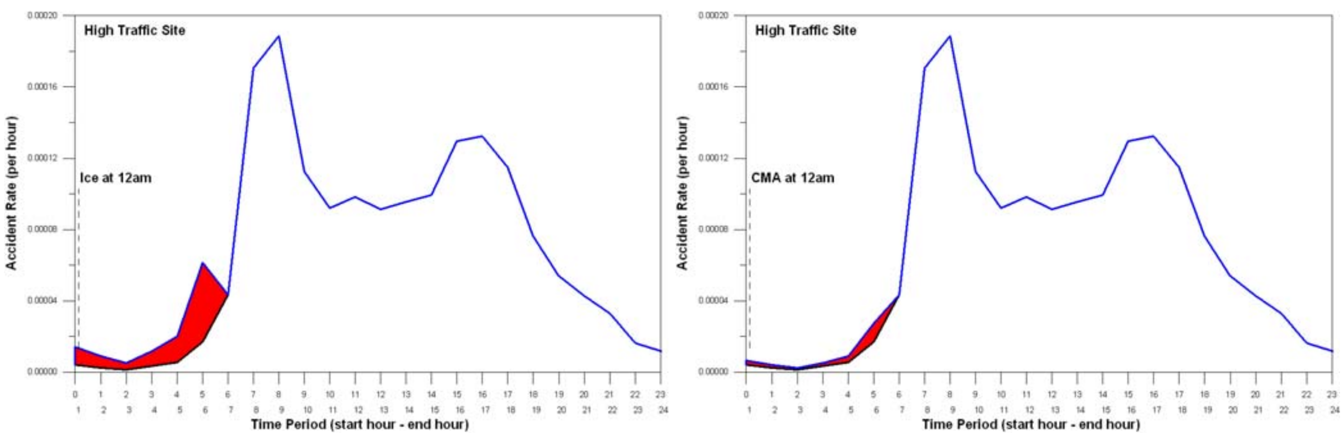


Figure 8.4 Ice and CMA at 12am



The plots in figures 8.1 to 8.4 show that the application of CMA represents a considerable reduction in the crash rate compared with an icy road, regardless of the timing of the application. However, application of CMA does represent an increase in the crash rate over a dry road condition until the CMA dries. Accordingly, to assess the relative effects of each of the treatments/road conditions at the different times, the hourly crash rates were summed for each scenario to provide a net daily crash rate. These are presented in table 8.2. The percentage differences in the daily crash rates for each of the treatments/road conditions compared with a dry road condition are given in table 8.3.

Table 8.2 Net daily crash rate – effects of treatment/road condition (number of crashes per day x10-3)

Treatment/road condition	Time of application							
	3pm		6pm		9pm		12am	
	High traffic	Low traffic	High traffic	Low traffic	High traffic	Low traffic	High traffic	Low traffic
Dry road (none)	1.64	0.29	1.64	0.29	1.64	0.29	1.64	0.29
Wet	1.92	0.35	1.78	0.33	1.69	0.30	1.65	0.30
Grit	2.10	0.39	1.86	0.34	1.71	0.31	1.66	0.30
CMA	2.10	0.39	1.86	0.34	1.71	0.31	1.66	0.30
Dewfall on CMA	2.03	0.38	1.83	0.33	1.70	0.30	1.65	0.30
Ice	3.21	0.63	2.33	0.44	1.85	0.33	1.73	0.31

Table 8.3 Effects of treatment/road condition compared with a dry road (% of dry road condition)

Treatment/road condition	Time of application							
	3pm		6pm		9pm		12am	
	High traffic	Low traffic	High traffic	Low traffic	High traffic	Low traffic	High traffic	Low traffic
Wet	118	120	109	111	103	103	101	100
Grit	128	133	113	116	104	104	101	101
CMA	128	133	113	116	104	104	101	101
Dewfall on CMA	124	127	111	114	104	104	101	101
Ice	196	214	142	149	113	112	105	104

To better compare the relative differences in daily crash rates between the different treatments or road conditions the data from tables 8.2 and 8.3 is plotted in figures 8.5 and 8.6 for the high and low traffic conditions.

Tables 8.2 and 8.3 show that the time at which a change in the road condition occurs, either through naturally occurring changes (rain, dewfall, frost and ice), or though application of treatments for frost and ice (grit or CMA), has a significant effect on the estimated number of daily crashes. As expected, when the treatments are made later in the evening, outside the rush hour period, when traffic levels are lower, the estimated daily crash rates are also much lower. After 9pm the overall daily crash rates for the two treatments for frost and ice (grit and CMA) are only slightly higher than those for a dry road, being less than 5% greater. They are also much lower than those for frost and ice conditions without treatment.

For the purposes of these comparisons it was assumed that the frost or ice conditions would last for a six-hour period, similar to the time that the grit or CMA treatments might reduce skid resistance to below the levels for a dry road. However, given temperatures consistently below freezing level, frost or ice conditions could last much longer, possibly through the morning traffic peak. This could significantly increase the daily crash rate for frost or ice conditions well above 200% levels.

Figure 8.5 Comparison of daily crash rates – high traffic site

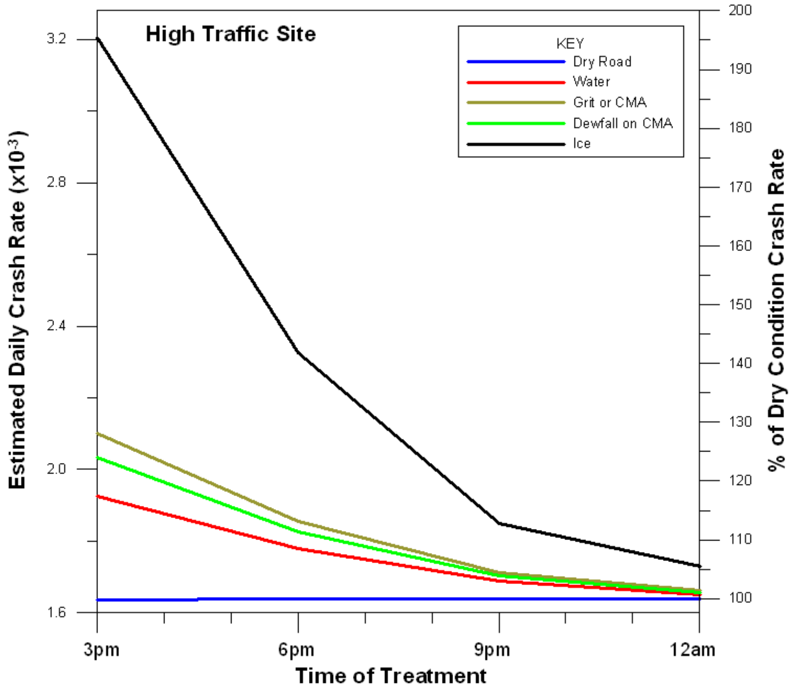
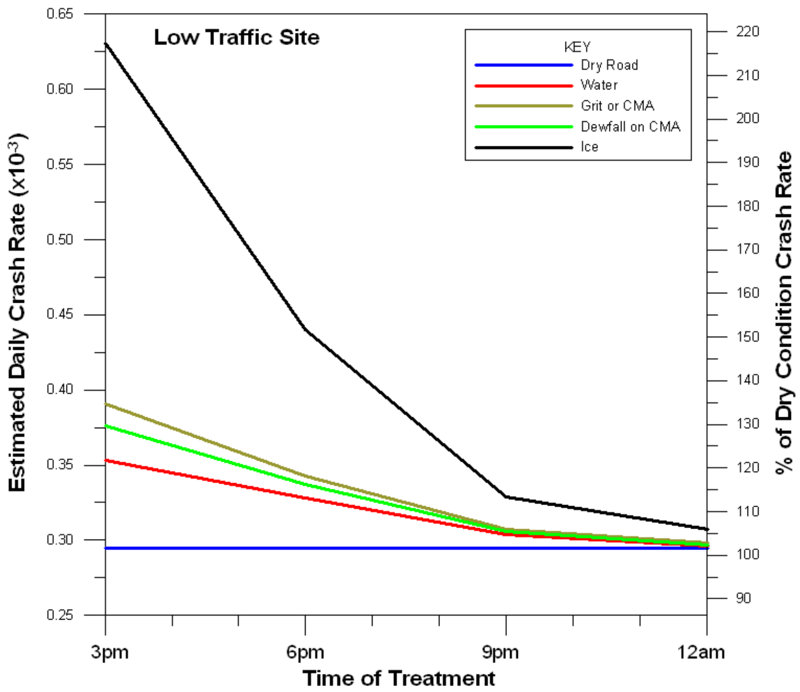


Figure 8.6 Comparison of daily crash rates – low traffic site



8.2 Timing of treatments for frost or ice

It was assumed for the purposes of the comparisons presented in the previous section that all the road condition changes and treatments occurred at the same time. However, application of grit is normally a reactive measure to frost or ice conditions that are already present. This means that the daily crash rate for gritting could be expected to be somewhat higher due to this period of frost or ice. In contrast CMA is normally applied proactively, when frost or ice is anticipated due to changing weather conditions. Accordingly, the daily crash rates could be expected to be similar to those indicated in table 8.2.

There are a large number of potential scenarios that could occur in these situations. For the purposes of illustrating the differences between: (a) doing nothing, (b) applying grit after ice/frost has begun to form, (c) applying CMA proactively on the expectation of frost or ice, and (d) applying CMA as a routine maintenance procedure, a representative scenario with different treatments was considered, as follows:

- A two-day period on the same high traffic site as used previously, where freezing conditions were expected each night, starting at 2am, with the potential for frost or ice to last through to mid-morning (10am).

The options considered were:

- no treatment – no frost or ice
- no treatment – frost and ice at 2am each night lasting until 10am
- application of grit at 3am each night (reacting to ice/frost)
- application of CMA at 12am on the first night in anticipation of frost and ice, with no application of CMA the following night, but assuming dewfall at 2am on the CMA already applied
- application of CMA at 9pm on the first night as part of a routine maintenance programme, no application the following night, and assuming dewfall at 2am on the CMA already applied.

Plots of the variation of the estimated crash rate with time were prepared for these different options. These are presented in figures 8.7 to 8.11. To assess the relative effects of each of the treatments or road conditions at the different times, the hourly crash rates are summed in table 8.4 for each scenario to provide a net daily crash rate.

Figure 8.7 Two-day scenario – dry road conditions

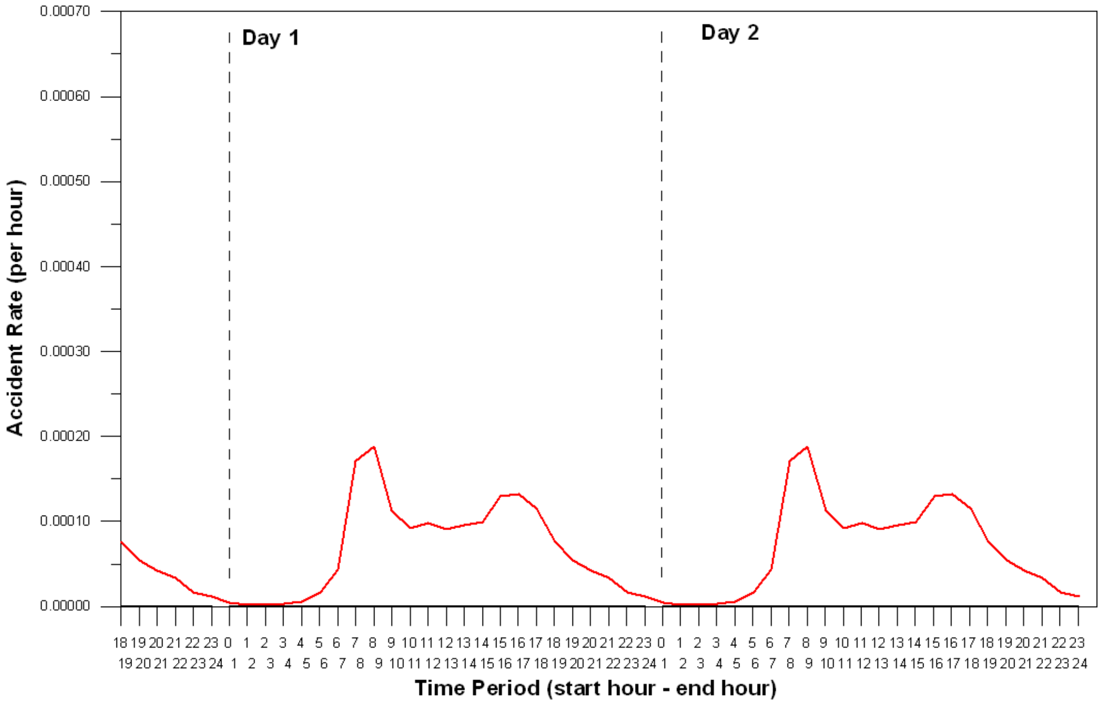


Figure 8.8 Two-day scenario – ice each night from 2am to 10am

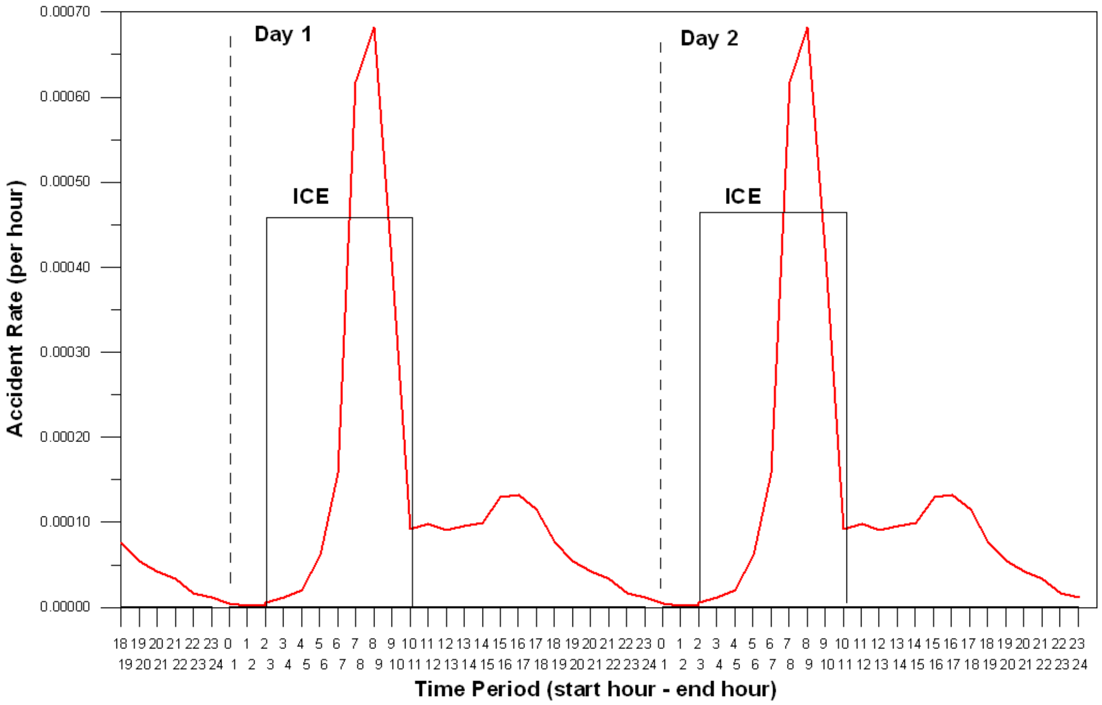


Figure 8.9 Two-day scenario – grit each night (reacting to ice/frost)

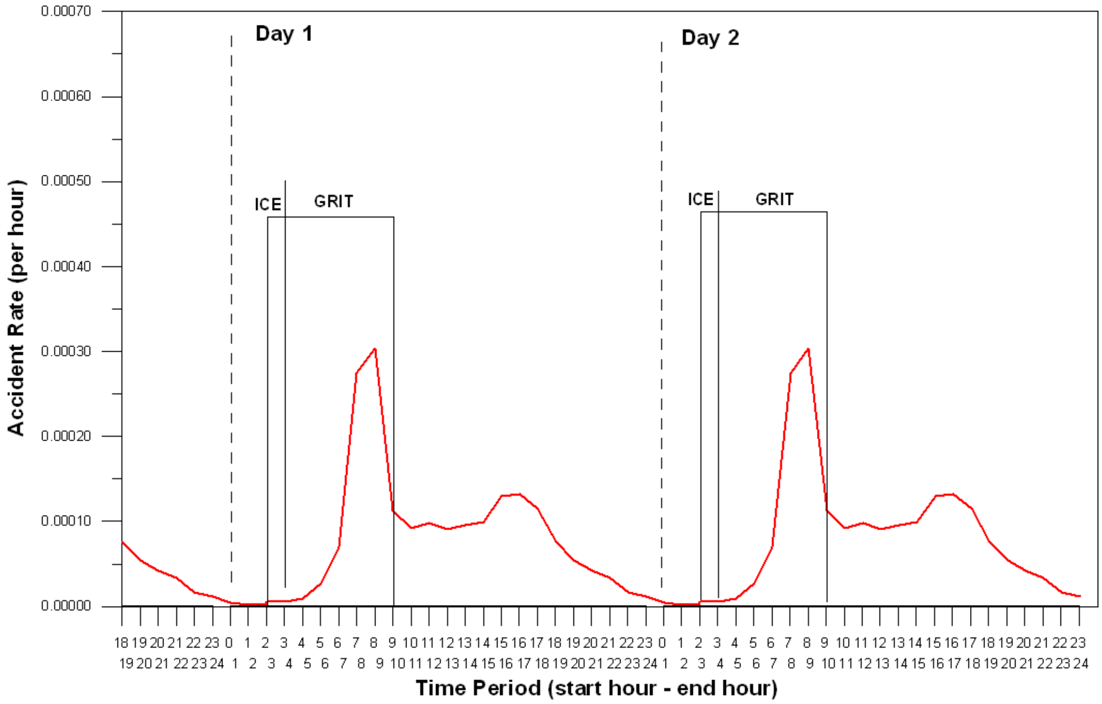


Figure 8.10 Two-day scenario – CMA first night, dewfall on CMA next night (application in anticipation of frost or ice based on meteorological data)

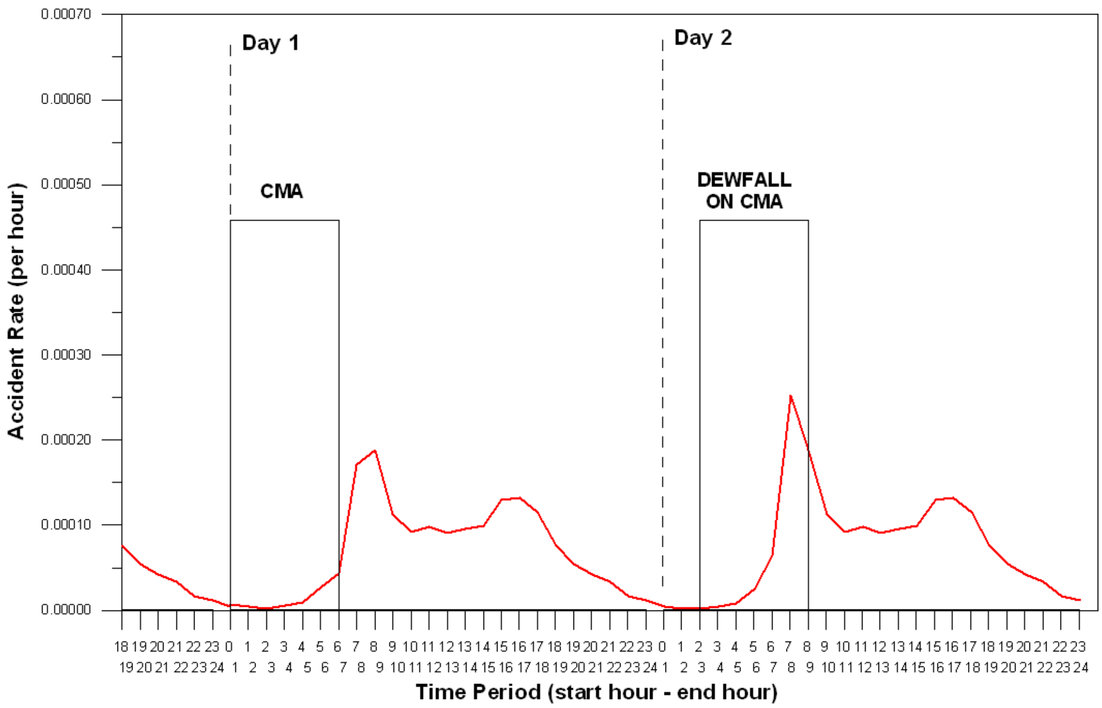


Figure 8.11 Two-day scenario – CMA first night, dewfall on CMA next night (application at 9pm as routine maintenance)

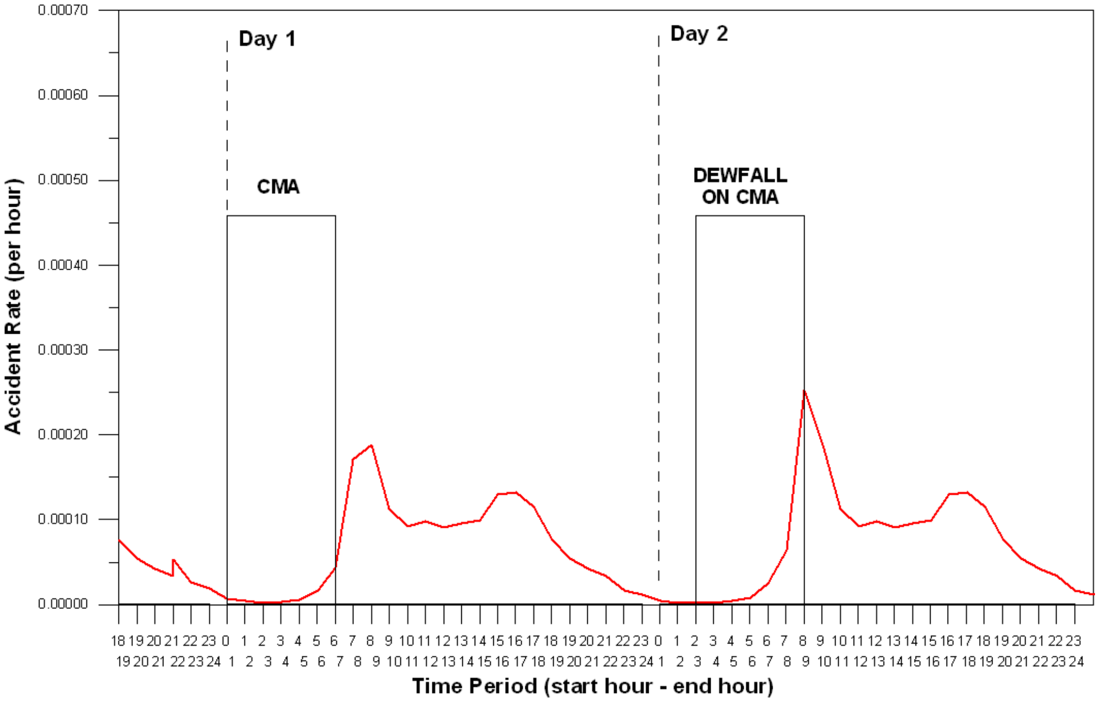


Table 8.4 Effects of treatment/condition over two days – high traffic site (estimated number of crashes over two days, x10-3)

Treatment/road condition	Estimated crash numbers
Dry	3.51
Ice	6.35
Grit	4.04
CMA (applied two hours before ice/frost anticipated)	3.65
CMA (applied at 9pm as standard maintenance)	3.70

Figures 8.7 to 8.11 and table 8.4 present similar trends to the single-day data and plots presented in section 8.1. The comparison of estimated crash rates over a two-day period shows that:

- not treating frost or ice represents a very marked increase in the crash rate/day
- treating with grit, or with CMA, either a short period before ice or frost is anticipated, or as a routine maintenance procedure at a specific time, reduces the crash rate per day considerably compared with frost or ice conditions
- there is very little difference between applying CMA a short period before ice or frost is anticipated, or as a routine maintenance procedure at a specific time, provided routine application avoids the rush hour peaks
- either application of CMA is better than an application of grit, given that grit is often applied after ice or frost has begun to form (although it is sometimes applied proactively before frost and ice has begun to form.

9 Conclusions and recommendations

Within the scope and limitations of this study involving the assessment of crash risk though combining the skid resistance changes following application of the anti-icing/de-icing agents CMA and mineral grit, and the variation of traffic levels with time, the following conclusions and recommendations have been made.

9.1 Conclusions

1 The programme of locked-wheel braking and GripTester measurements of skid resistance on different road surfaces under different conditions (dry, wet) and following application of the two main treatments for frost and ice (CMA and mineral grit) showed that:

- there was considerable variation in the stopping distances, and average and peak skid resistances across the different surfaces, treatments and road conditions
- almost all the changes in the road conditions investigated, including applications of water, CMA and mineral grit reduced the skid resistance to levels below those for a dry road on all of the different surfaces. The exception was CMA when dry
- there was considerable variation in the levels of skid resistance with all of the treatments, on similar road surfaces
- the reductions in skid resistance were generally greater on the smoother textured asphalt surfaces (OGPA and asphaltic concrete) than on the more textured asphalt surfaces (slurry seals) and chipseals
- CMA and grit generally performed worse on the smoother asphalt surfaces than on chipseals.
- the performance of CMA with time after application was heavily dependent on environmental conditions such as temperature, humidity and wind. Good drying conditions or drainage increased the skid resistance with time after application. Cool conditions, high humidity and little wind tended to slow down this change
- when CMA was dry, it performed as well as or better than a dry road surface
- dewfall tended to reactivate the CMA, causing skid resistance to reduce, but not to the same degree as when first applied
- the performance of grit with time after application tended to improve as the grit was crushed or moved by the action of traffic
- under cool conditions with high humidity, following an application of water, CMA or mineral grit, the skid resistance might take up to six hours to rise to levels approaching those of a dry road.

2 The daily traffic data for the test sites used for the locked-wheel braking tests indicated that:

- there was relatively little variation in the traffic levels during week days (Monday to Friday)

- there were the expected peaks in traffic levels during the morning and early evening ‘rush hour’ periods
- the variations in weekend daytime traffic levels were generally different from those occurring on weekdays, with traffic tending to peak more during the middle of the day.

3 Combining the changes in skid resistance that can occur with a change in road conditions (application of water, CMA or grit) with the expected crash rates derived from the Cenek, Davies and Henderson (2005) crash risk model, and the measured traffic levels, to produce an assessment of the expected crash risk, showed that:

- the time at which a change in road conditions occurred, either naturally because of rain, dewfall, frost or ice, or through application of treatments for frost and ice (grit or CMA) would have a significant impact on the expected number of daily crashes
- expected crash rates were much higher for frost and ice than for any other road conditions or treatments
- crash rates under all of the different changes in road conditions, except for frost and ice, were much lower when these changes occurred outside the peak traffic period in the early morning and early evening. After 9pm the expected daily crash rates for all roads where the condition had changed because of water, CMA or grit were less than 5% greater than for a dry road
- treating road surfaces with grit, or with CMA, either a short period before ice or frost was anticipated, or as a routine maintenance procedure at a specific time, reduced the crash rate per day considerably compared with untreated frost or ice conditions
- there was very little difference (1–2%) in the expected crash rate as a result of applying CMA a short period before ice or frost was anticipated, and applying it as a routine maintenance procedure at a specific time, provided the routine application avoided the rush hour peaks
- either of the two applications of CMA was better than an application of grit, given that grit was applied near to or after the time ice or frost had begun to form.

9.2 Recommendations

1 A comparison of the actual crash rates should be made between roads in similar areas (a) not treated with CMA and (b) treated with CMA or grit. This study should also consider whether there are any differences between the rates in urban and rural areas, and between areas where the environmental conditions are different, eg Central and Coastal Otago.

2 That the results of this study form part of a discussion between roading agencies regarding best practice guidelines for winter maintenance and in particular the application of CMA and grit and the resulting benefits and risks.

10 References

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Appendix A

Selected test sites – site and surface photos

Figure A.1 View looking towards the northeast (increasing direction)

Figure A.2 View of surface (also shows tyre skid mark – mineral grit)

Site 1: SH1 (Abbotts Creek) – RP 715/2.5 (decreasing direction) – OGPA

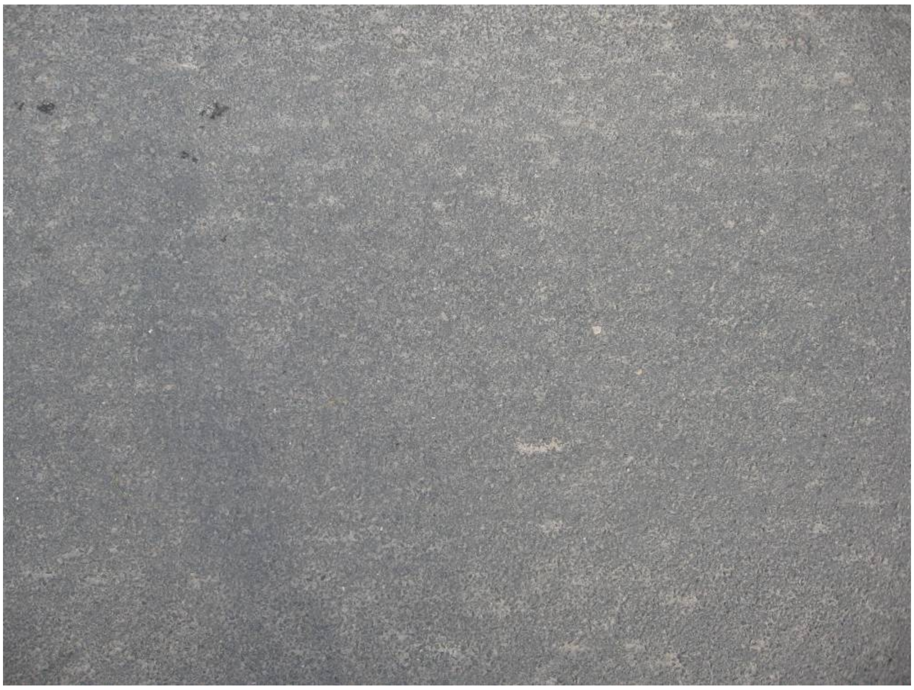
Figure A.3 View looking towards the northeast (decreasing direction)

Figure A.4 View of surface

Site 2: SH87 (south of Mosgiel) – RP 0/4.3 – coarse chipseal

Figure A.5 View looking towards the north (decreasing direction)

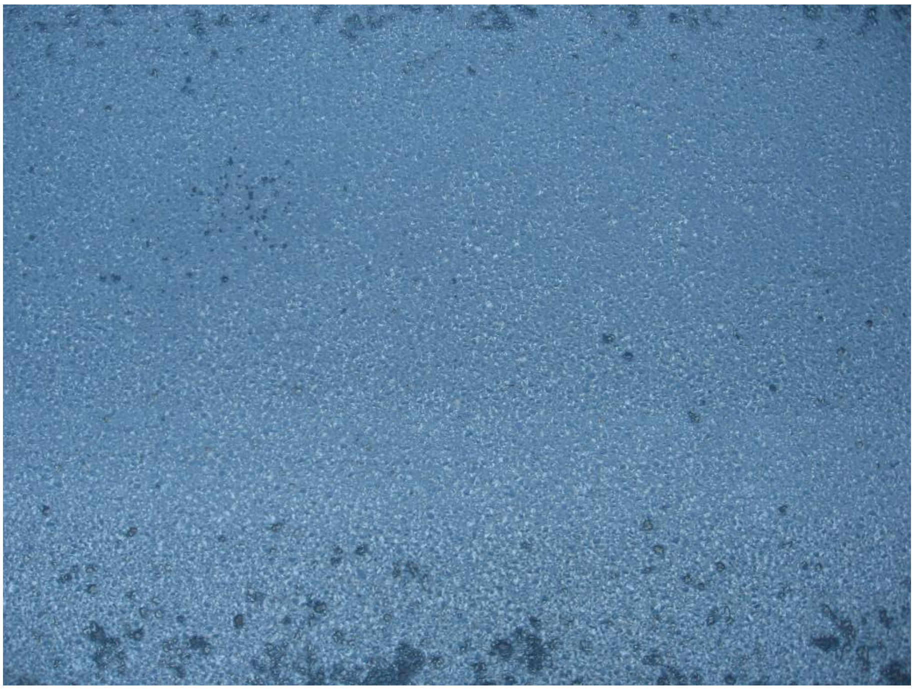
Figure A.6 View of surface



Site 3: SH87 (Outram) – RP 0/12.75 – slurry seal

Figure A.7 View looking uphill towards the west

Figure A.8 View of surface



Site 4: DCC – Stuart Street – mix 10 AC

Figure A.9 View looking downhill towards the west

Figure A.10 View of surface

Site 5: DCC – Three Mile Hill – second coat chipseal (Grade 4)

Figure A.11 View looking to the southwest (increasing direction)

Figure A.12 View of surface

Site 6: SH1 (Dunedin one-way system) – RP 706/1.2 – slurry seal

Figure A.13 View looking towards the west

Figure A.14 View of surface

Site 7: MacAndrew Rd (South Dunedin) – asphaltic concrete

Appendix B

Selected test sites – traffic data plots

Figure B.1 Site 1: SH1 (Abbotts Creek) – RP 715/2.5 (decreasing direction) - OGPA

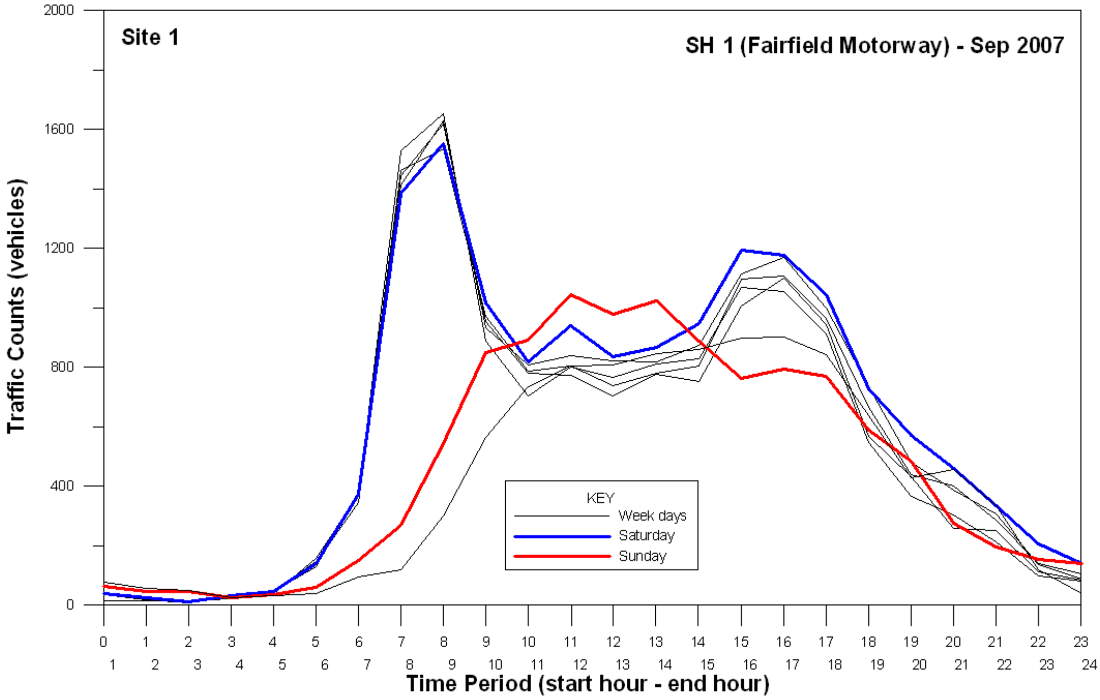


Figure B.2 Site 2: SH87 (South of Mosgiel) – RP 0/4.3 – coarse chipseal

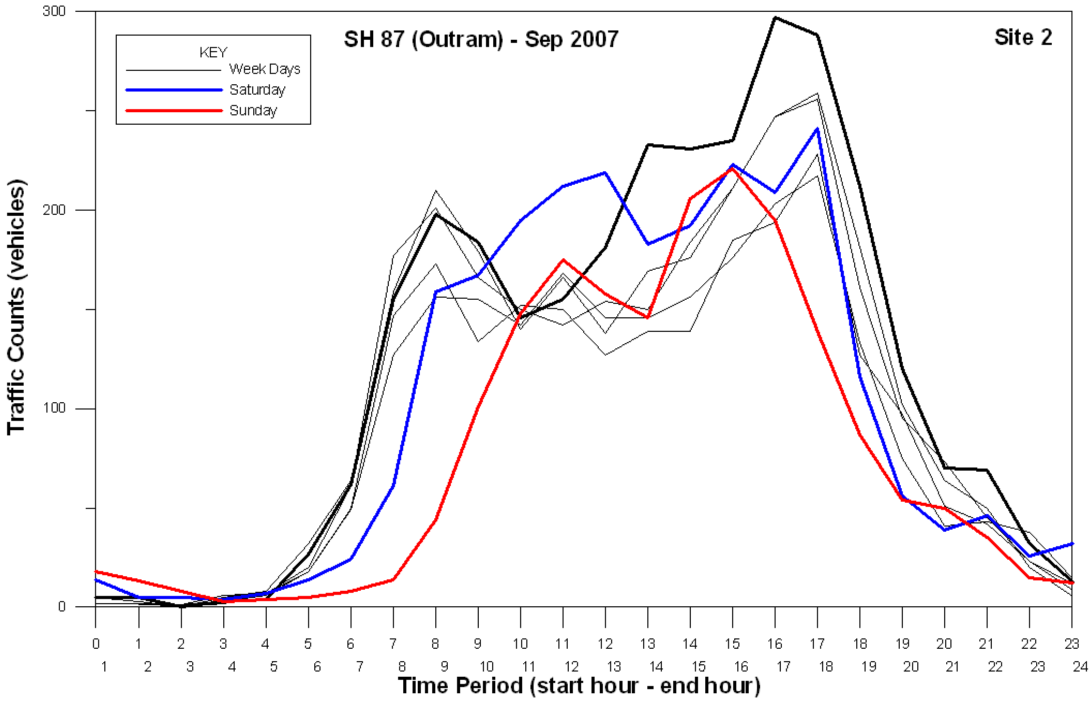


Figure B.3 Site 3: SH87 (Outram) – RP 0/12.75 – slurry seal

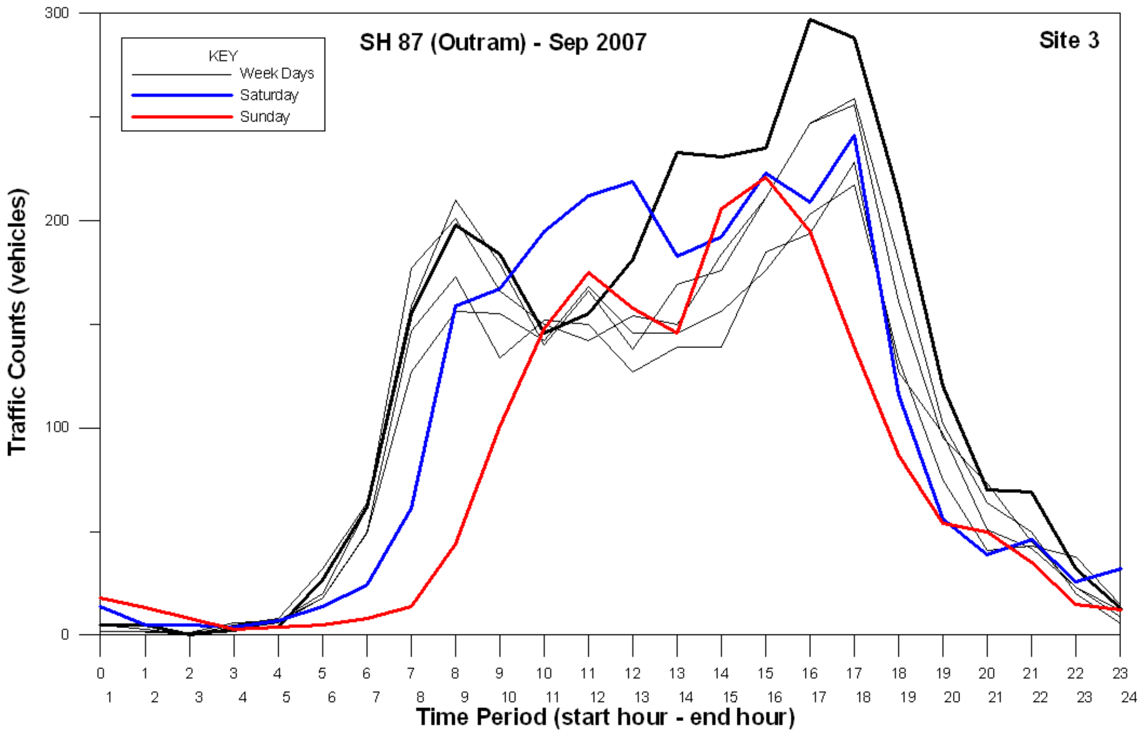


Figure B.4 Site 4: DCC – Stuart St – mix 10 AC

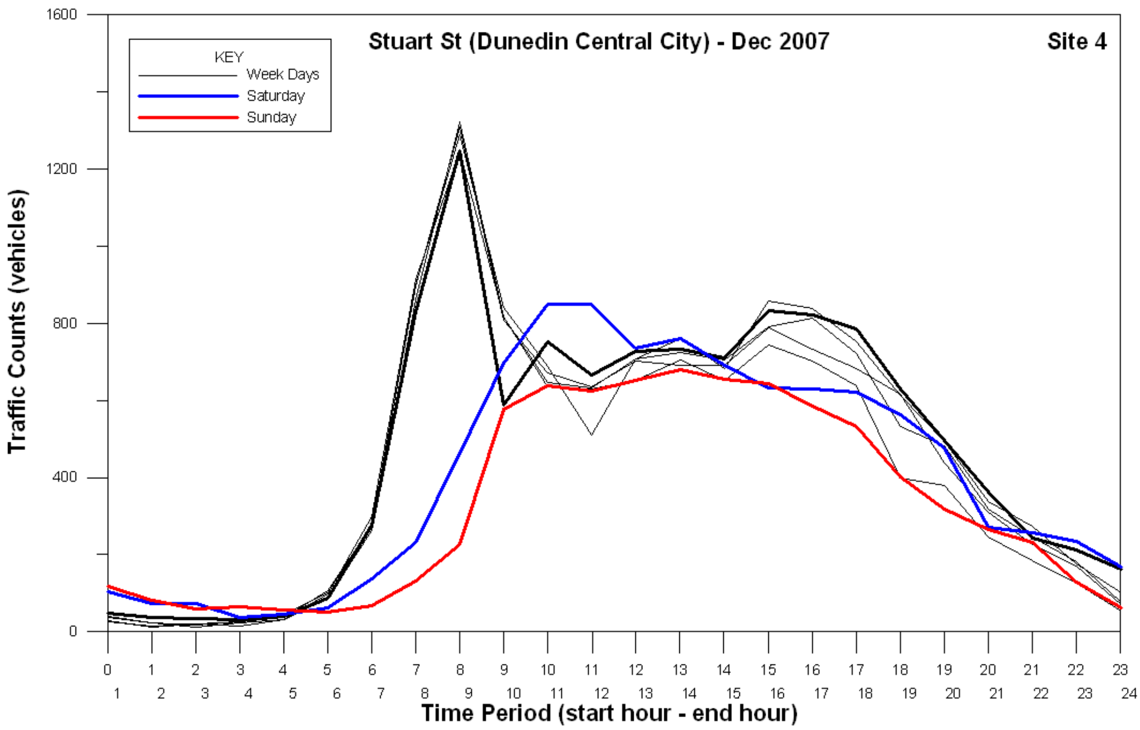


Figure B.5 Site 5: DCC – Three Mile Hill – second coat chipseal (Grade 4)

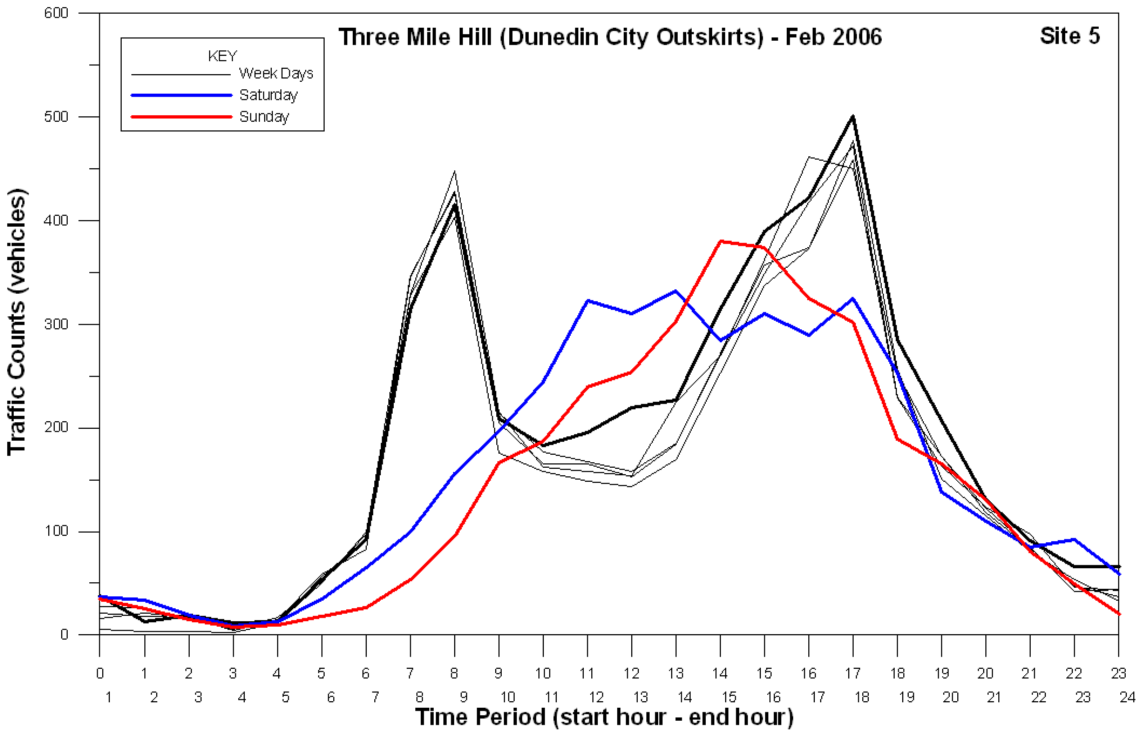


Figure B.6 Site 6: SH1 (Dunedin one-way system) – RP 706/1.2 – slurry seal

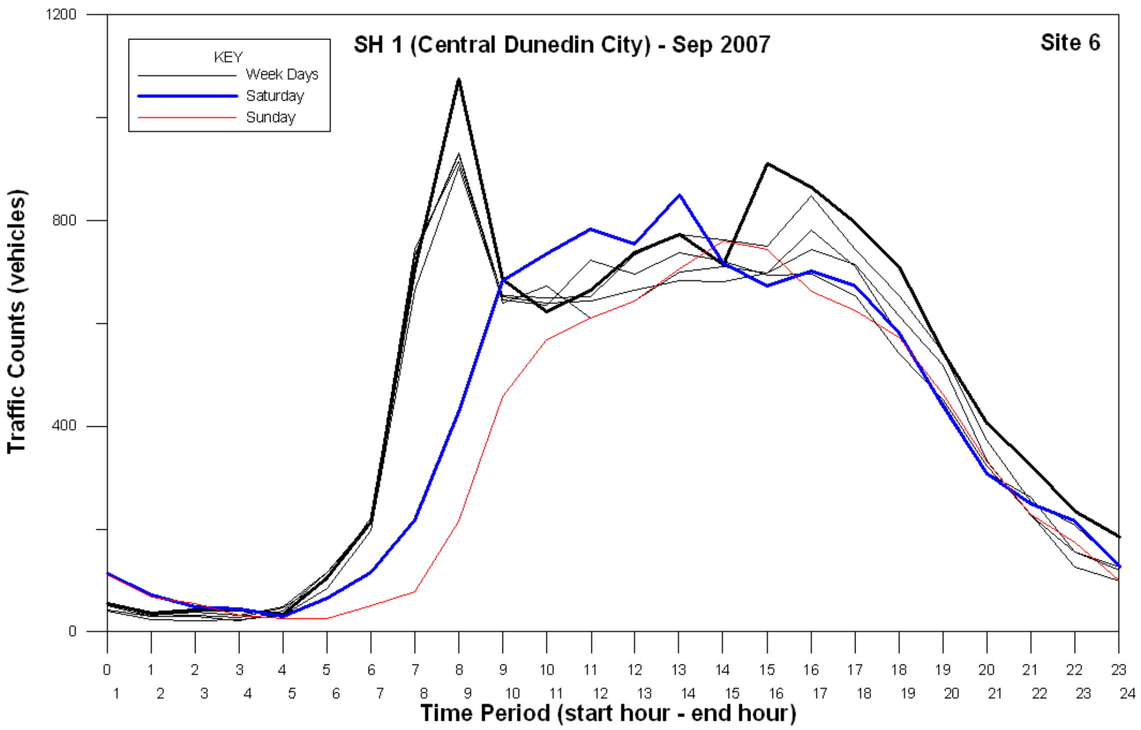
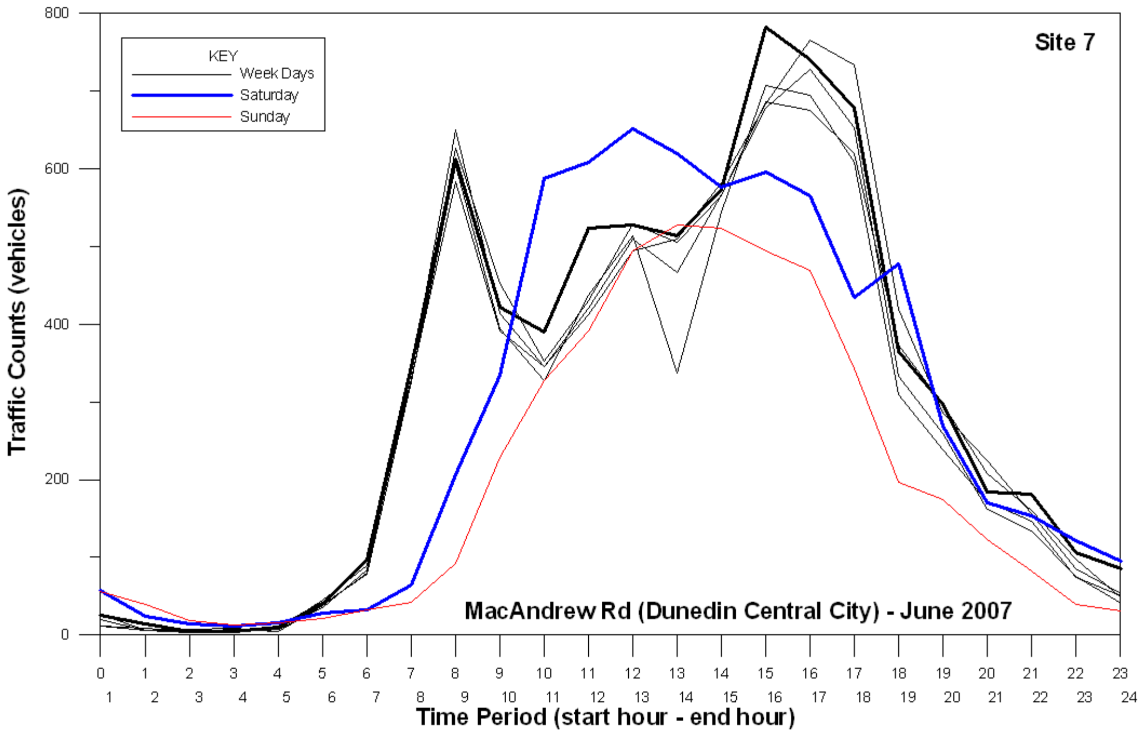


Figure B.7 Site 7: MacAndrew Rd (South Dunedin) – asphaltic concrete

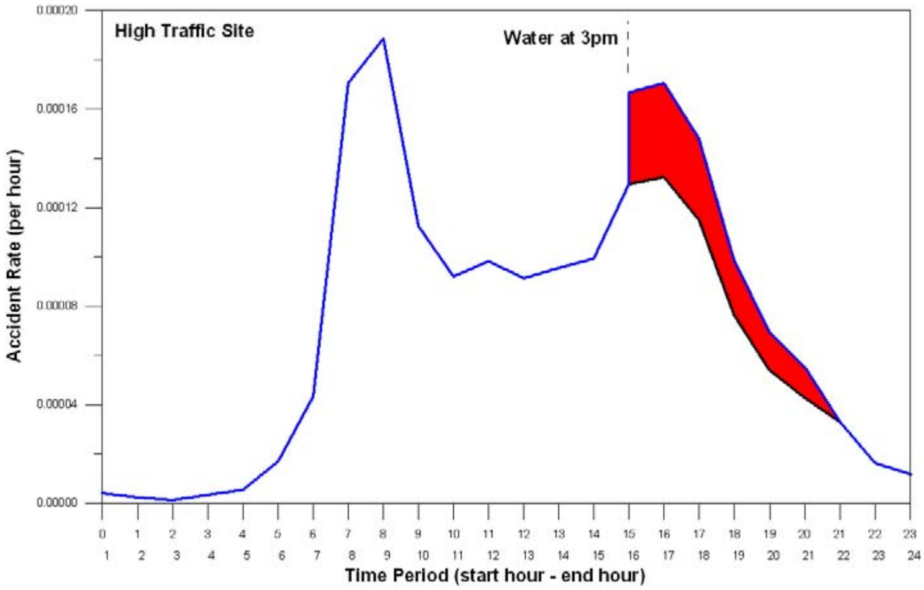


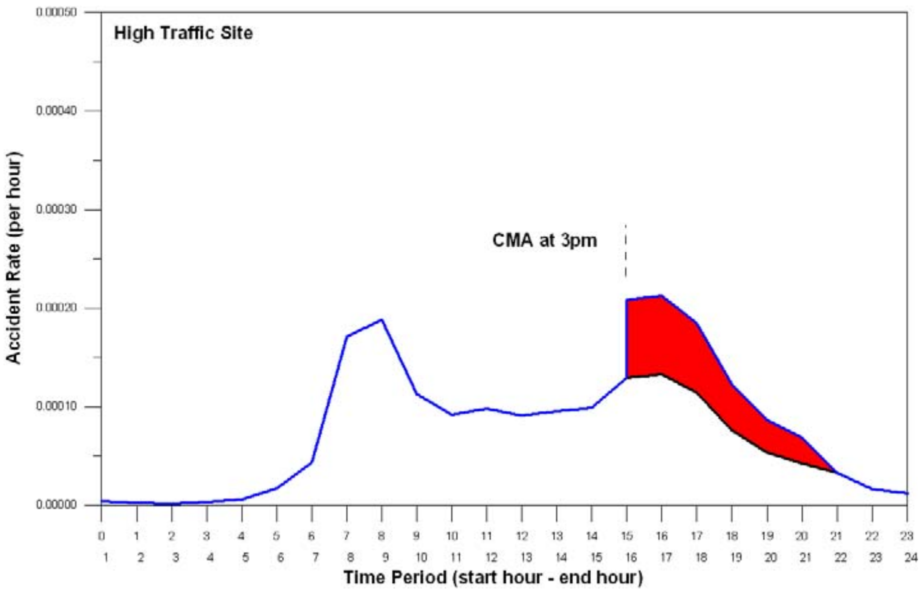
Appendix C

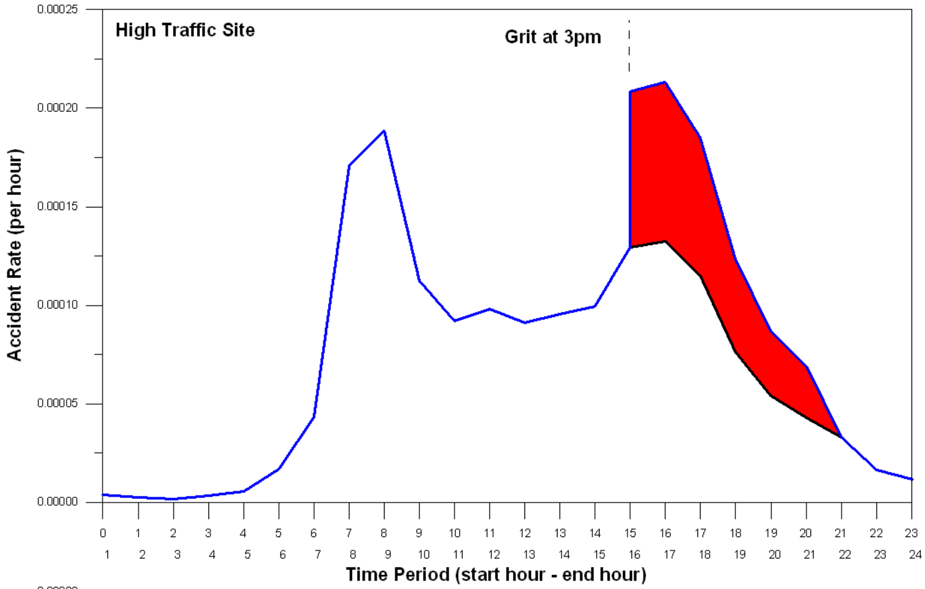
Crash rates – treatments on high and low traffic sites

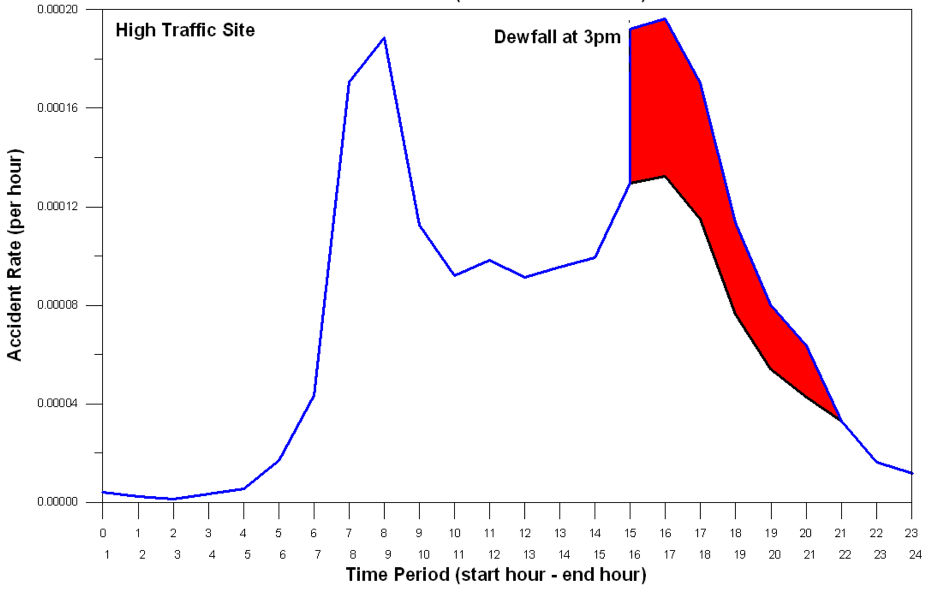
The following plots present comparisons of the estimated crash rates for different treatment and conditions (water, CMA, grit, dewfall on CMA, and ice) at different times of the day (3pm, 6pm, 9pm and 12am) against the dry road condition. Only the data for one of the most highly trafficked and one of the most lowly trafficked test sites are presented. The red area highlights the difference between the dry road condition and the treatment/condition.

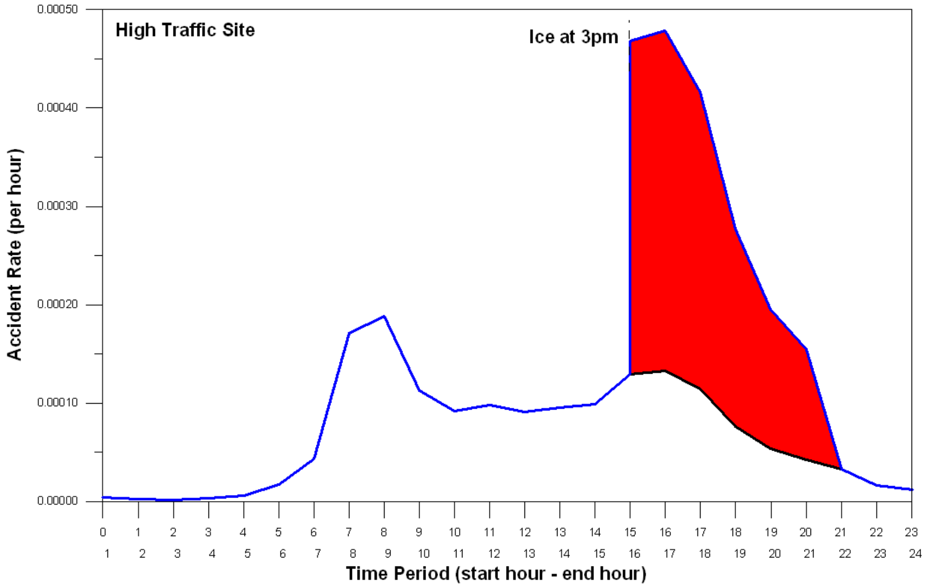
High traffic site – 3pm



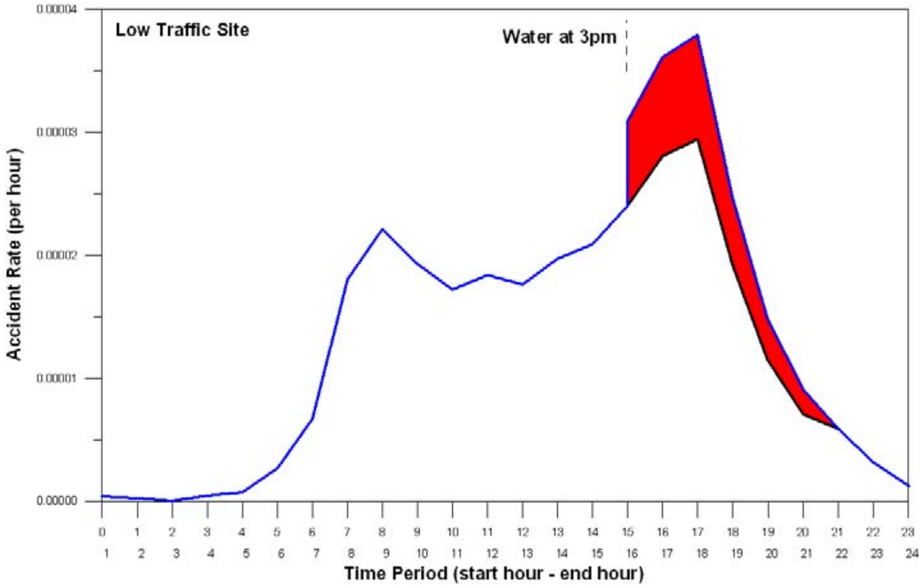


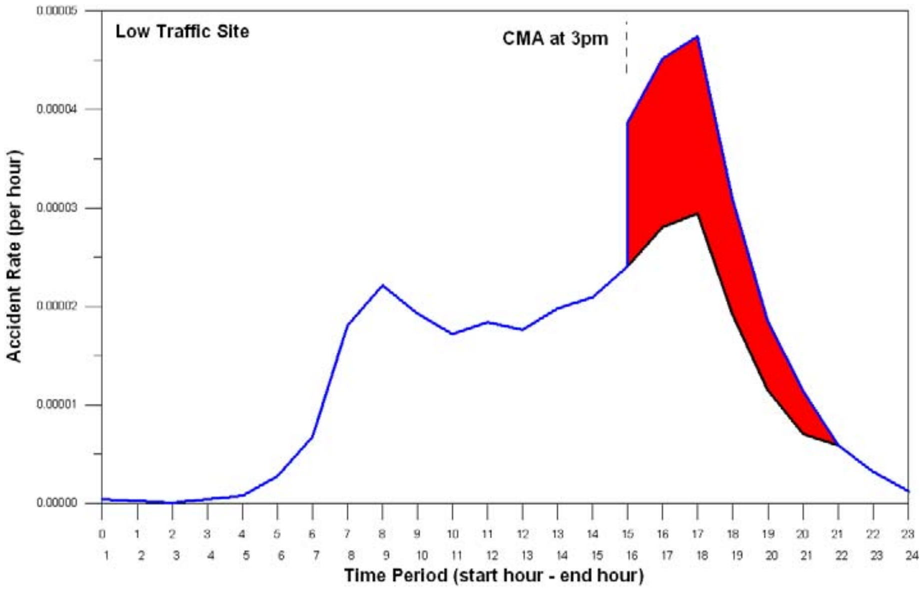

High Traffic Site
Grit at 3pm
Accident Rate (per hour)
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
Time Period (start hour - end hour)

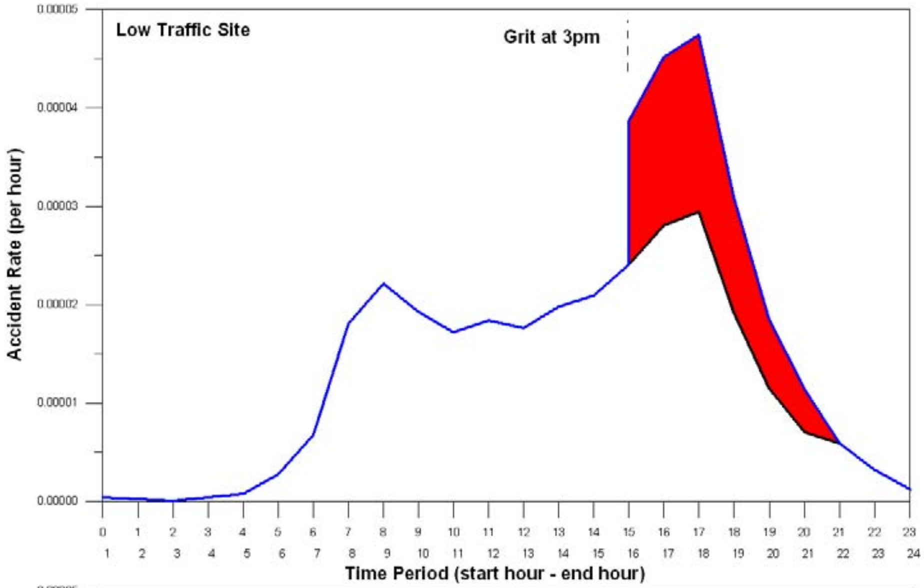

High Traffic Site
Dewfall at 3pm
Accident Rate (per hour)
0.00020
0.00016
0.00012
0.00008
0.00004
0.00000
Time Period (start hour - end hour)

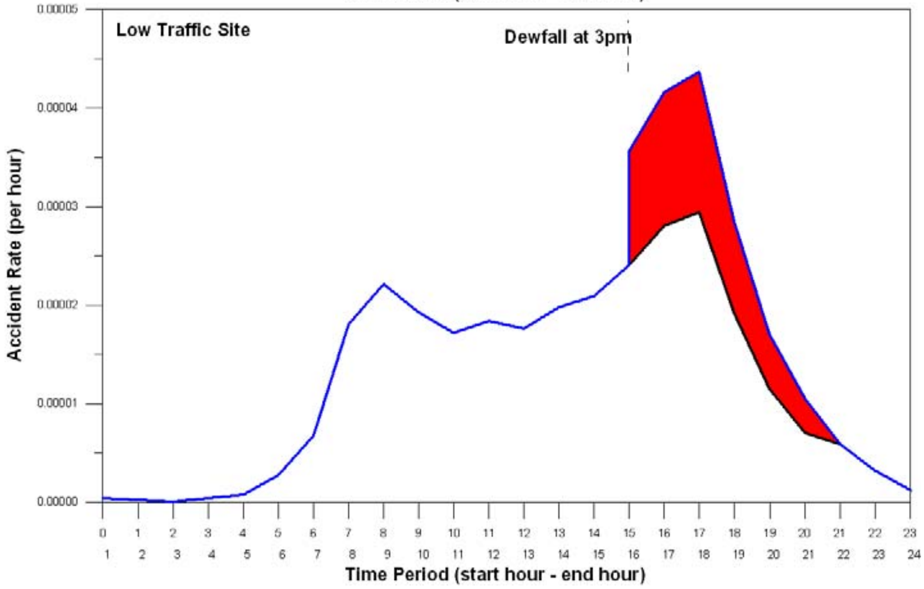

High Traffic Site
Ice at 3pm
Accident Rate (per hour)
0.00050
0.00040
0.00030
0.00020
0.00010
0.00000
Time Period (start hour - end hour)

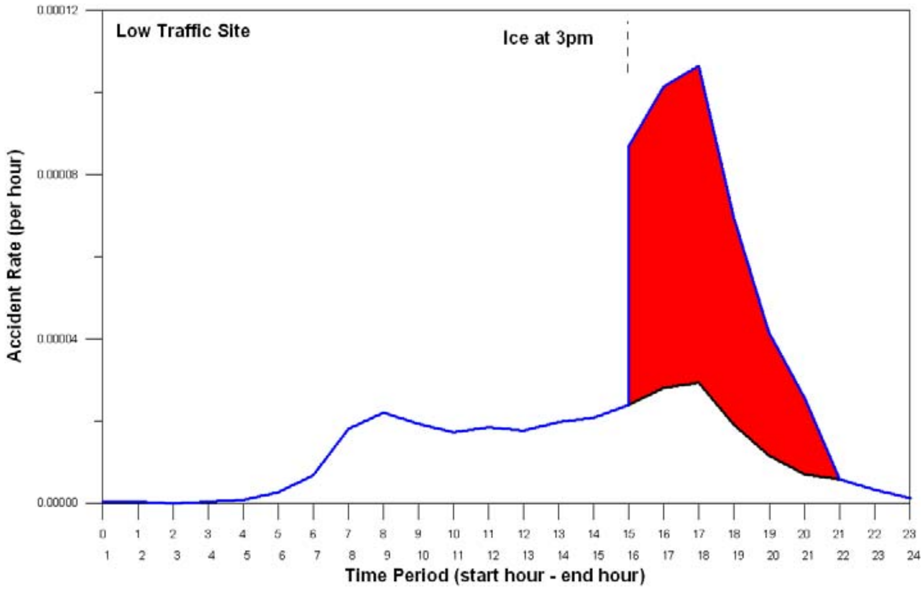
Low traffic site – 3pm



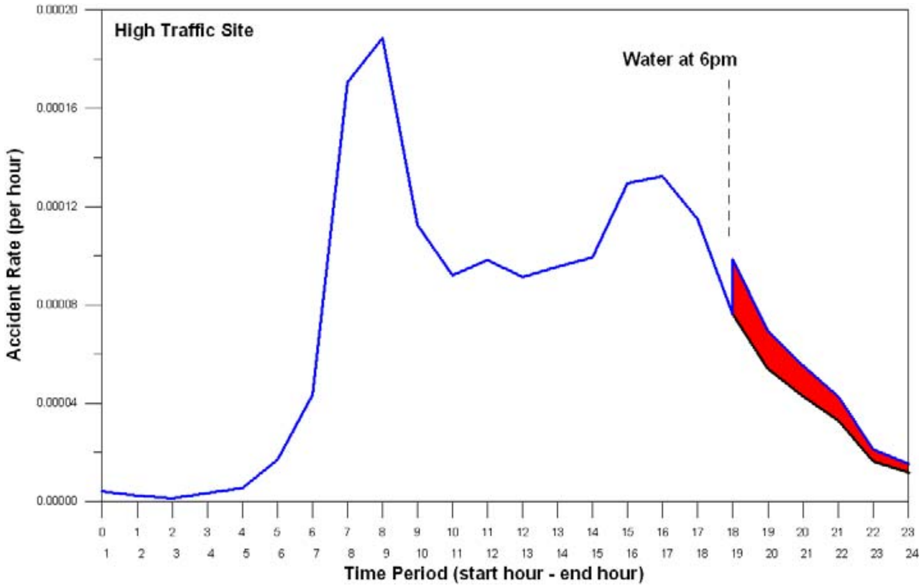


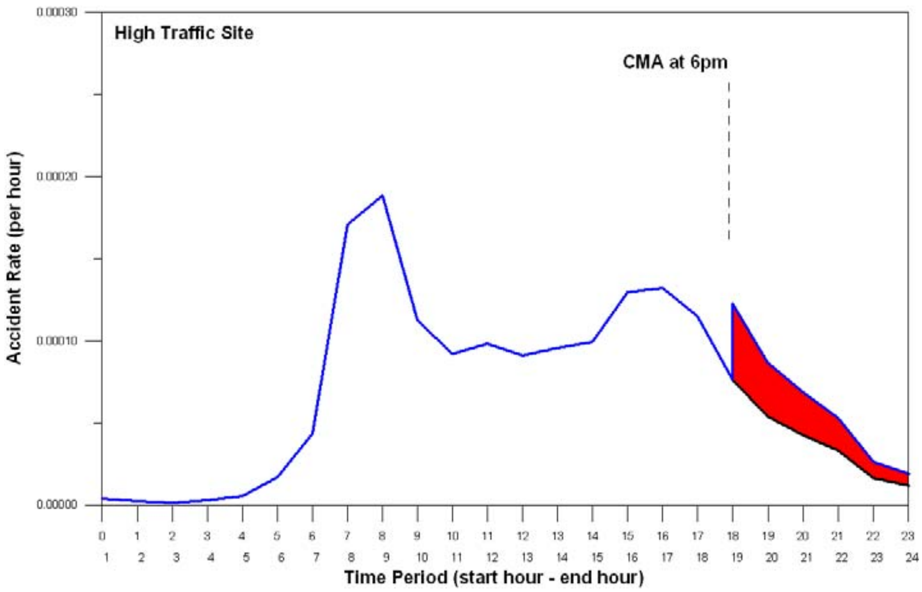

Low Traffic Site
Grit at 3pm
Accident Rate (per hour)
0.00000
0.00001
0.00002
0.00003
0.00004
0.00005
Time Period (start hour - end hour)

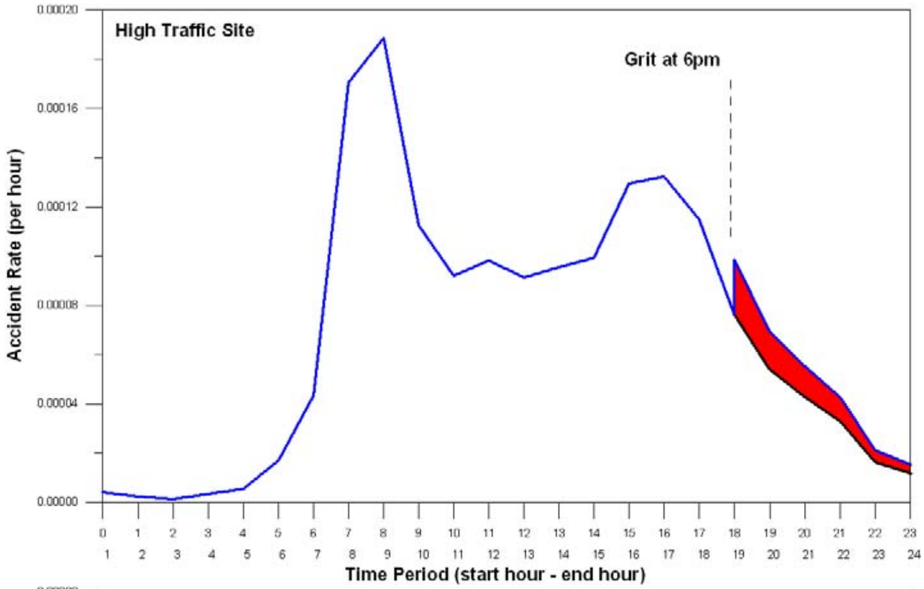

Low Traffic Site
Dewfall at 3pm
Accident Rate (per hour)
0.00000
0.00001
0.00002
0.00003
0.00004
0.00005
Time Period (start hour - end hour)

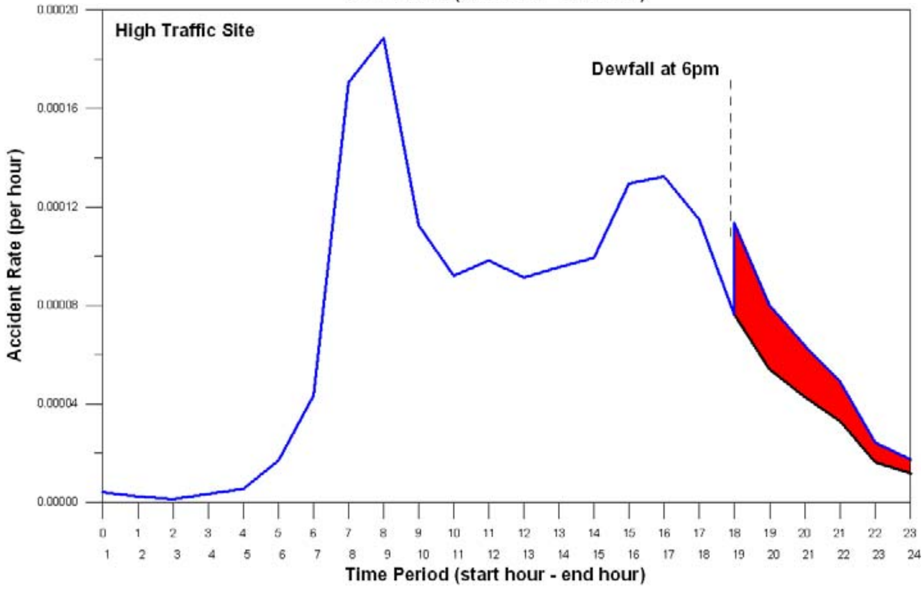

Low Traffic Site
Ice at 3pm
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
Time Period (start hour - end hour)

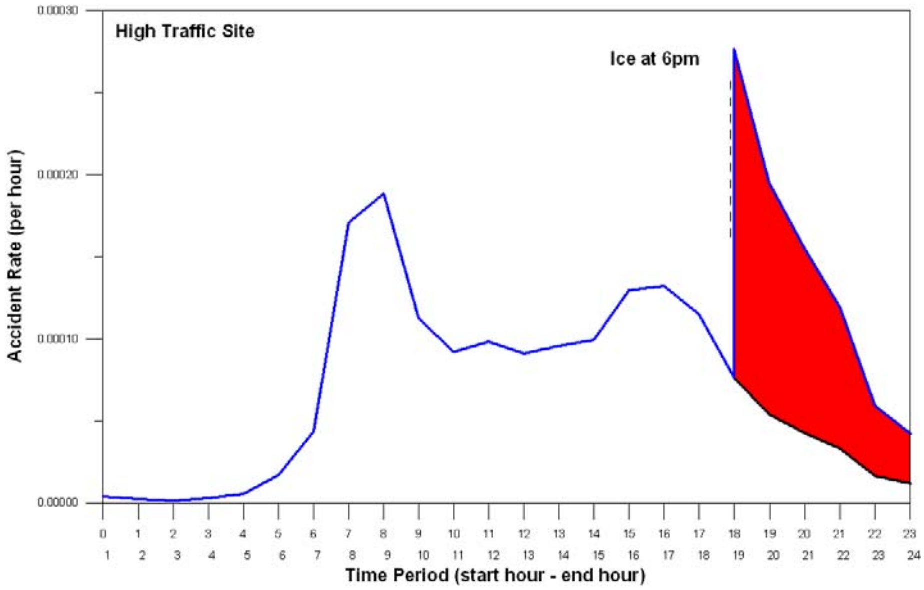
High traffic site – 6pm



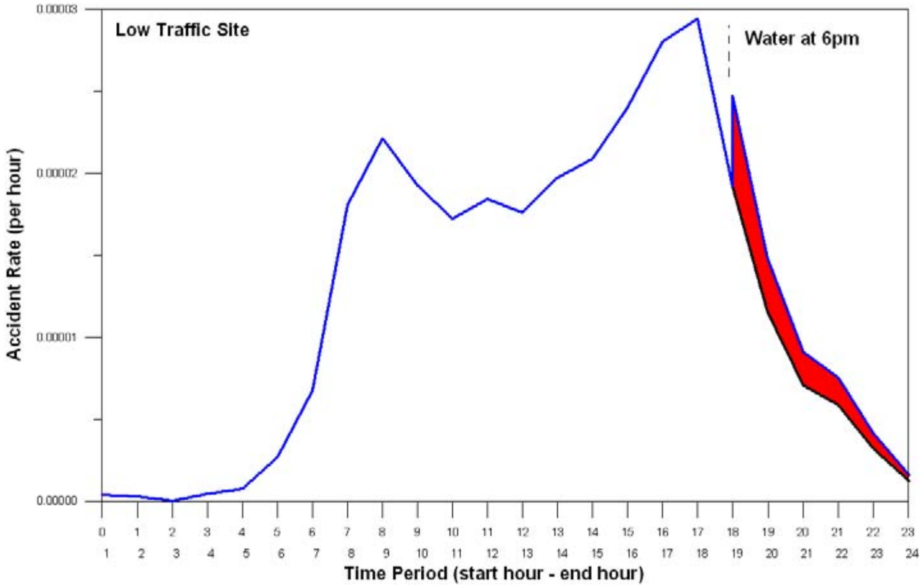


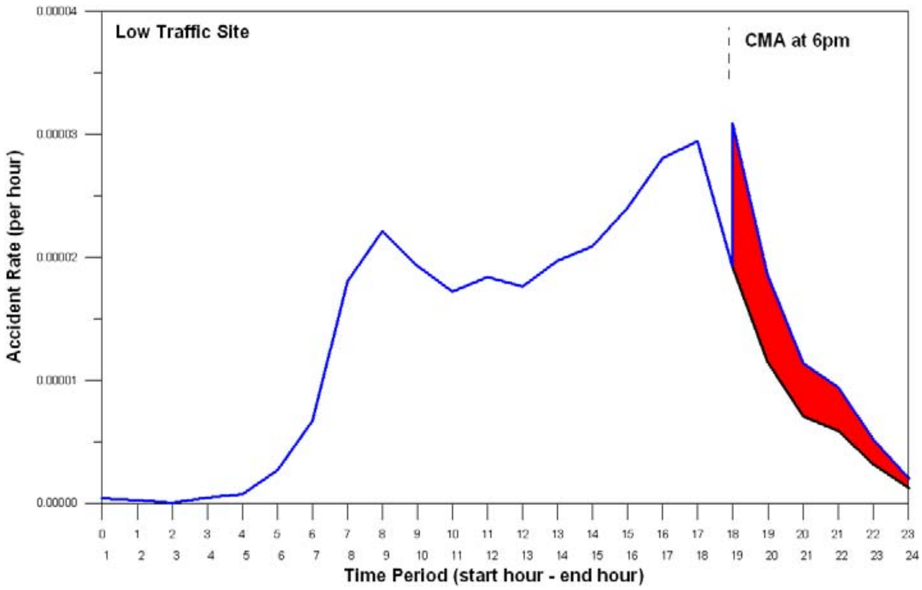

High Traffic Site
Grit at 6pm
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

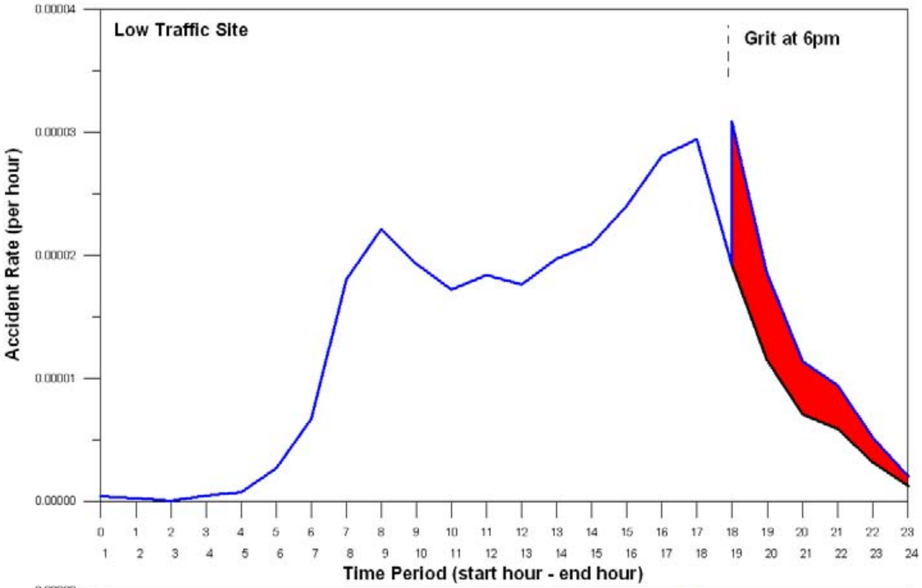

High Traffic Site
Dewfall at 6pm
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

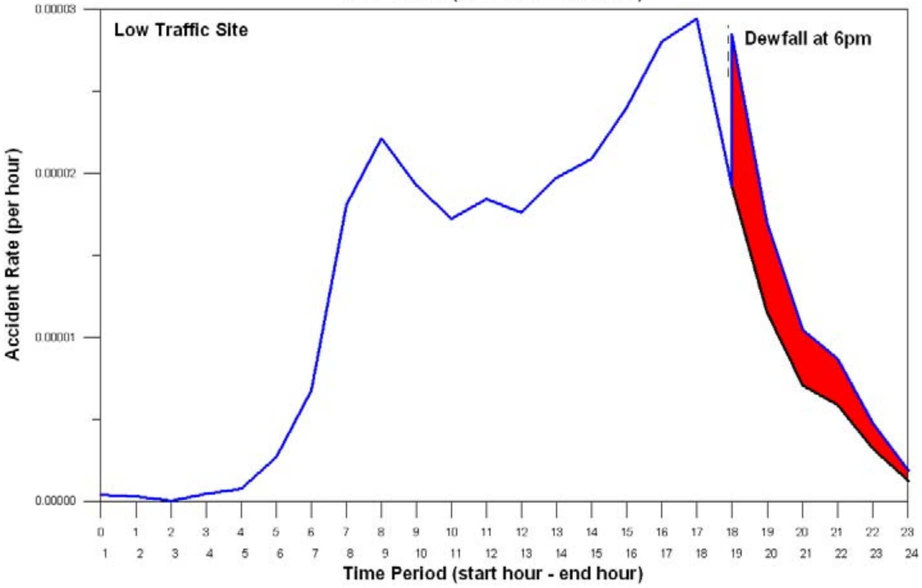

High Traffic Site
Ice at 6pm
Accident Rate (per hour)
0.00000
0.00010
0.00020
0.00030
Time Period (start hour - end hour)

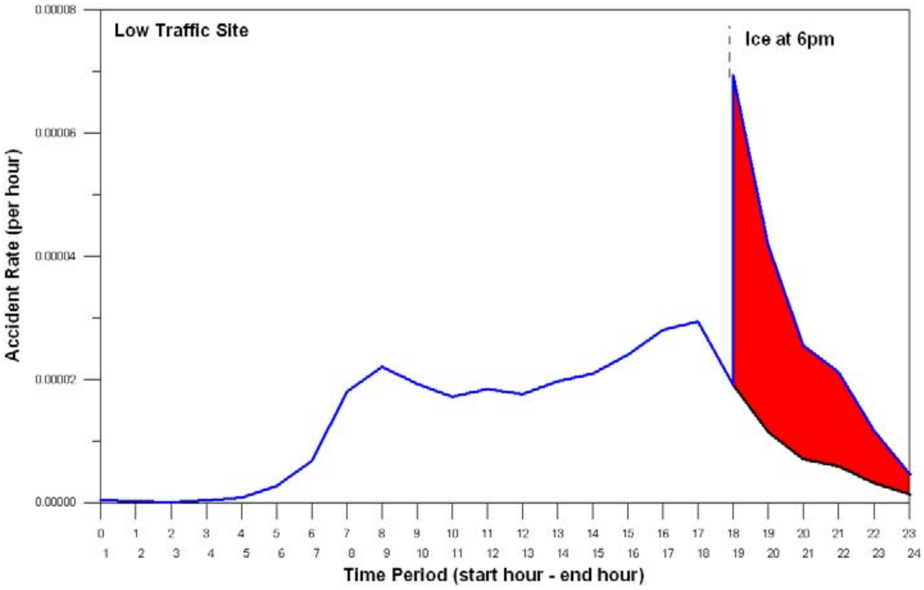
Low traffic site – 6pm



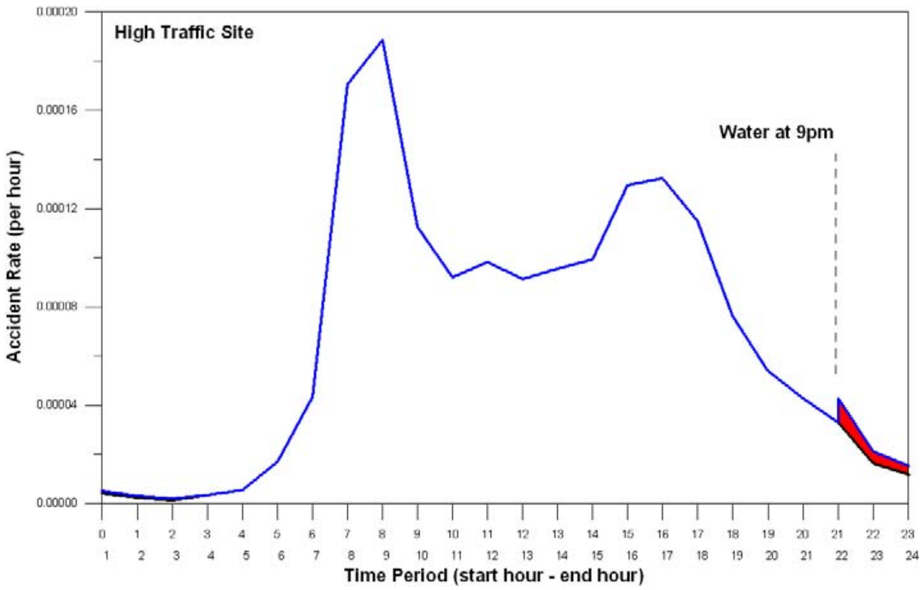


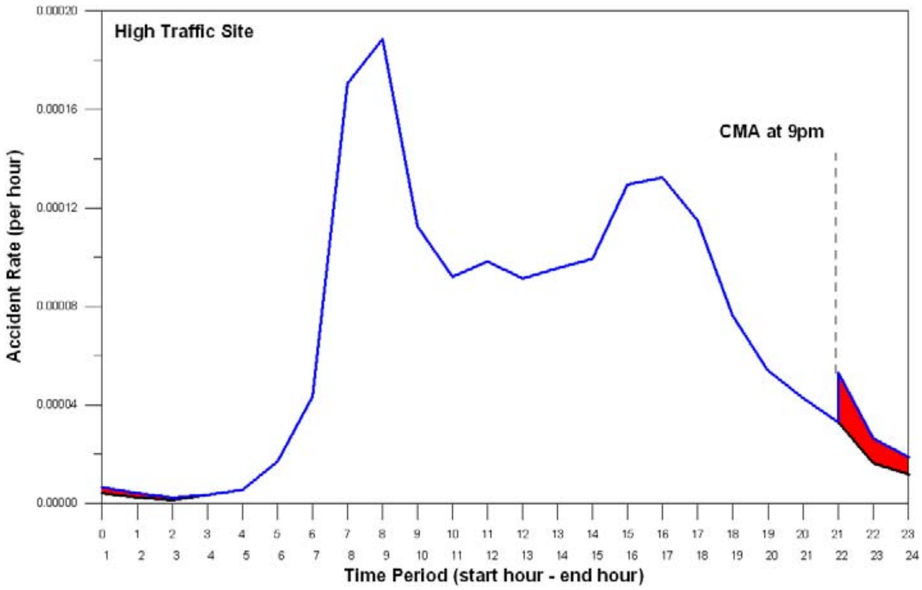

Low Traffic Site
Grit at 6pm
Accident Rate (per hour)
Time Period (start hour - end hour)

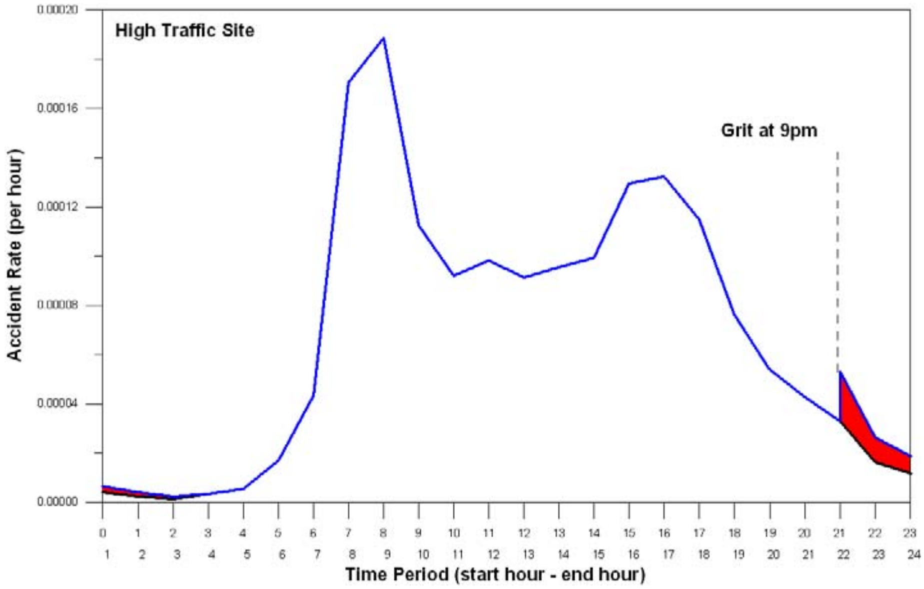

Low Traffic Site
Dewfall at 6pm
Accident Rate (per hour)
Time Period (start hour - end hour)

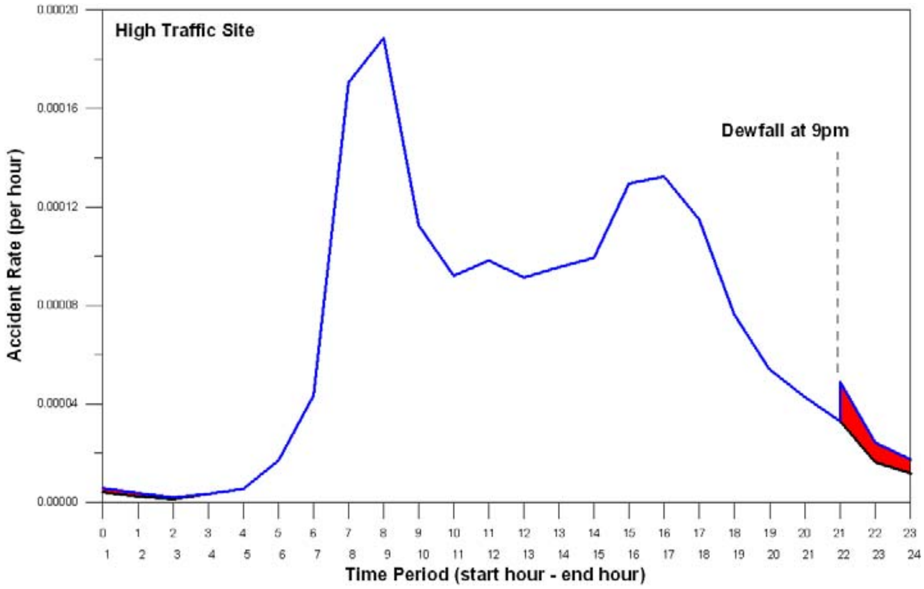

Low Traffic Site
Ice at 6pm
Accident Rate (per hour)
Time Period (start hour - end hour)

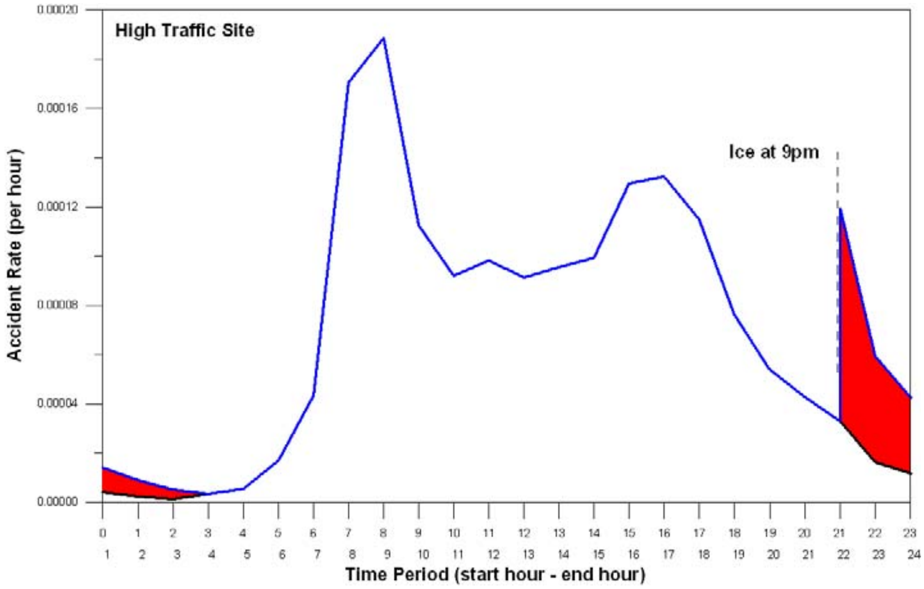
High traffic site – 9pm



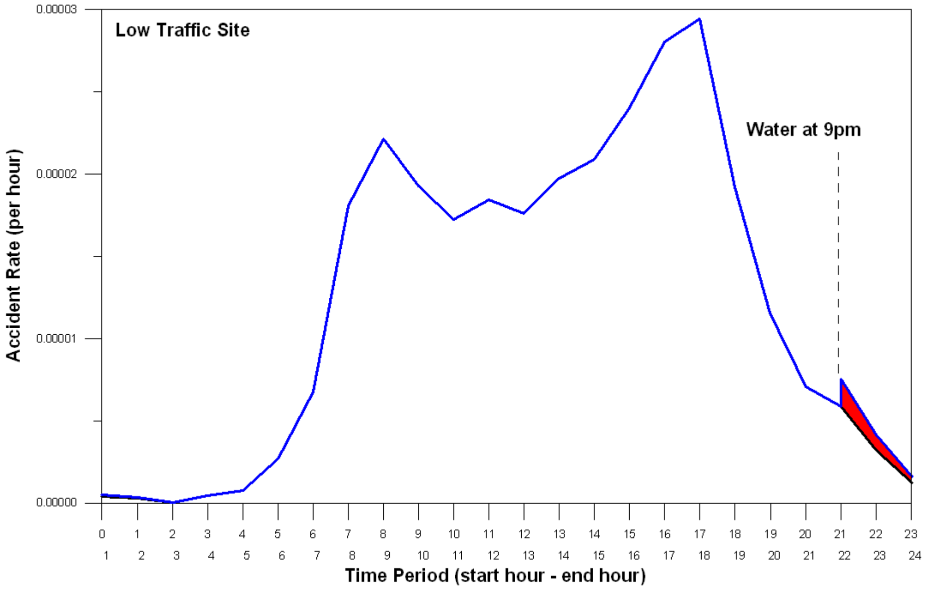


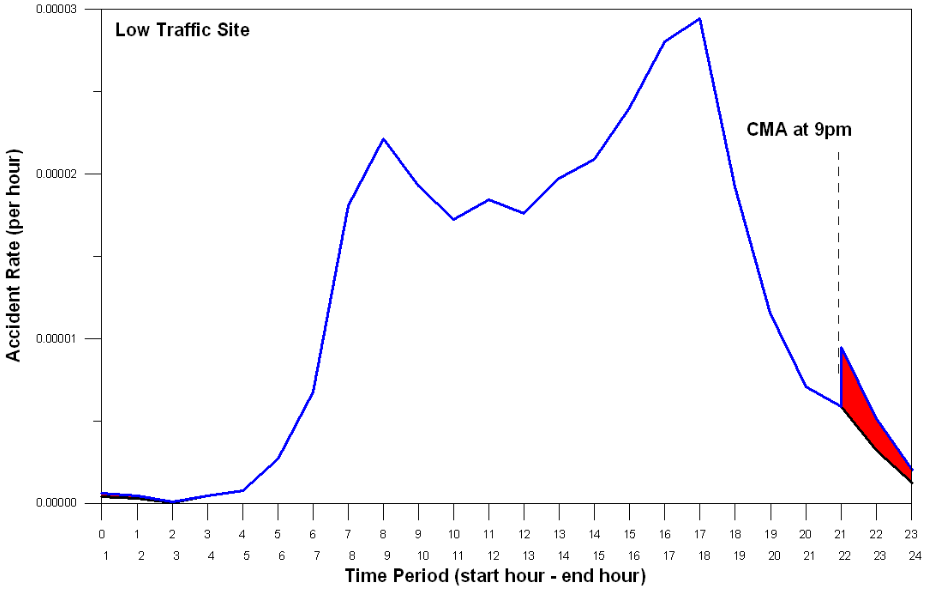

High Traffic Site
Grit at 9pm
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

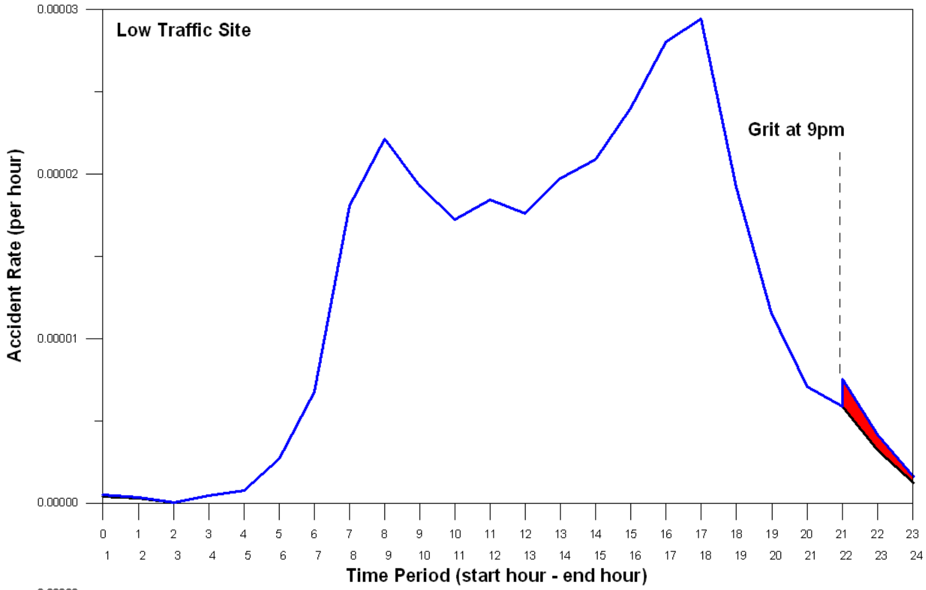

High Traffic Site
Dewfall at 9pm
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

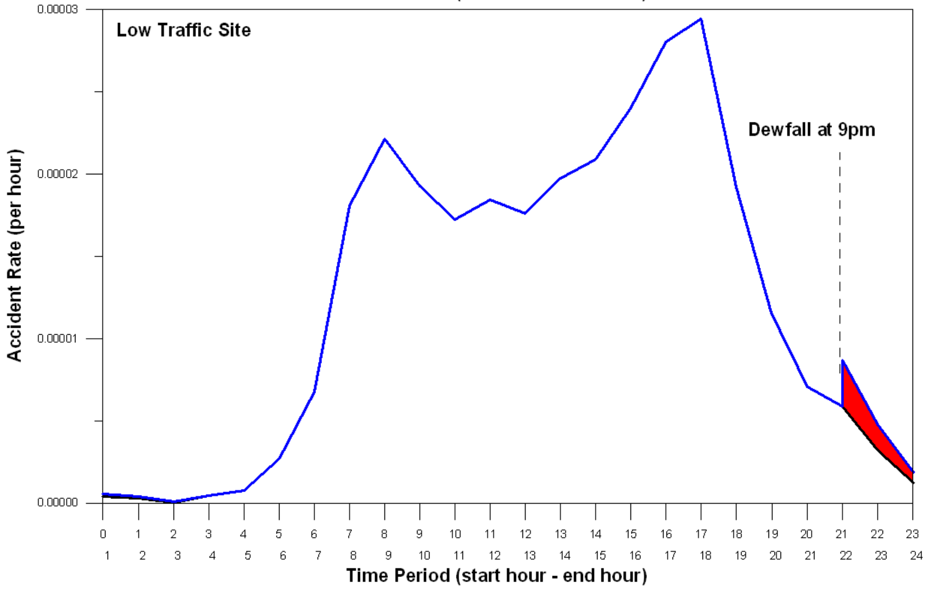

High Traffic Site
Ice at 9pm
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

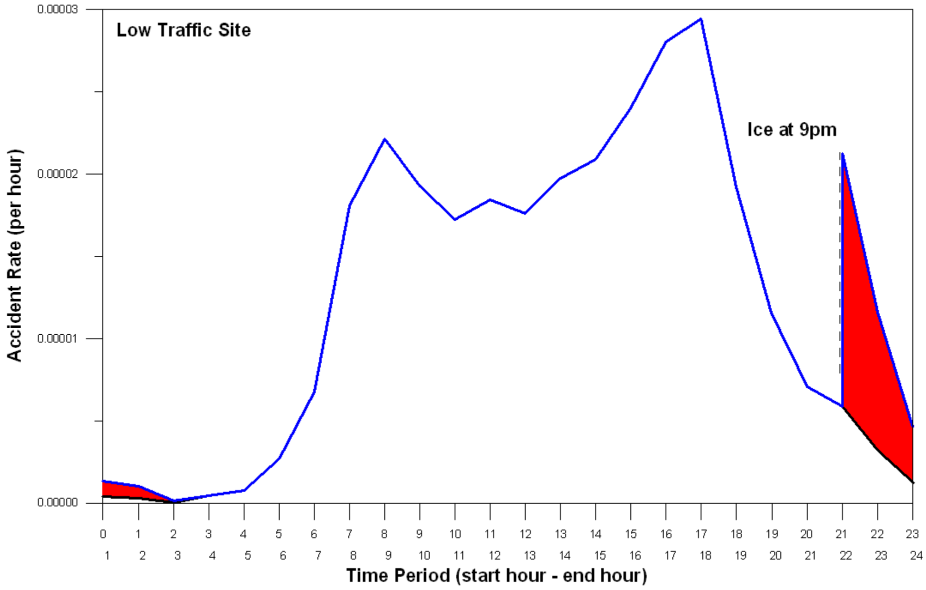
Low traffic site – 9pm



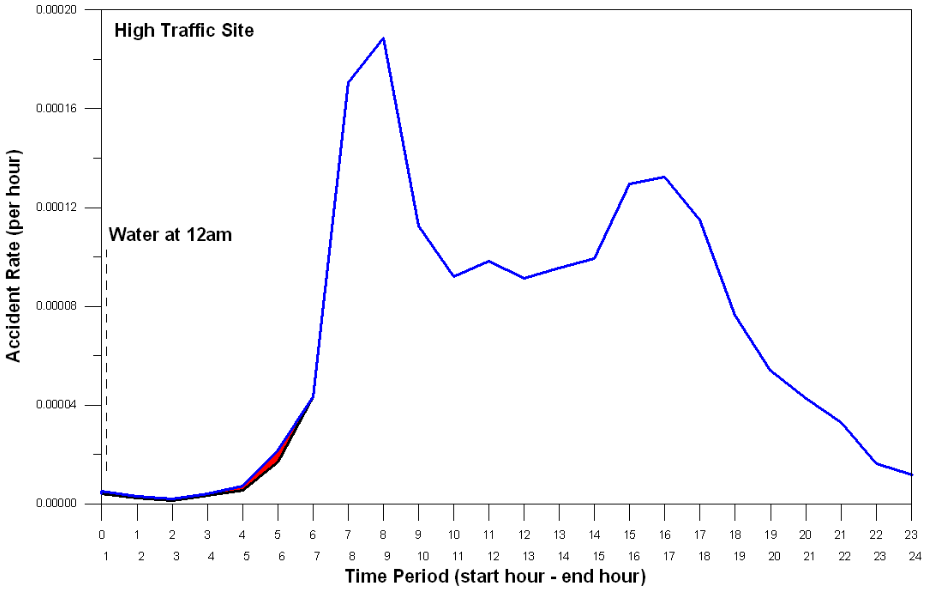


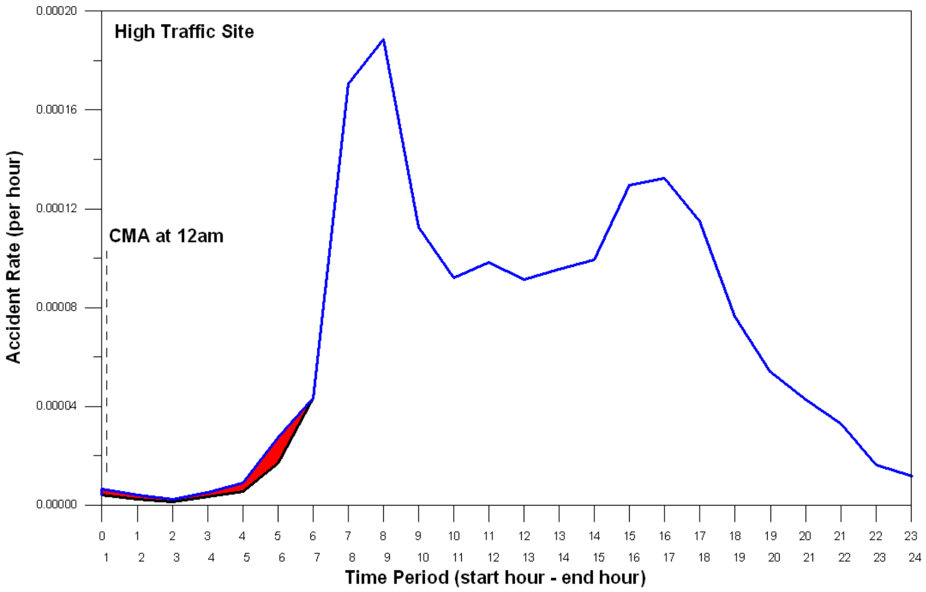

Low Traffic Site
Grit at 9pm
Accident Rate (per hour)
0.00003
0.00002
0.00001
0.00000
Time Period (start hour - end hour)

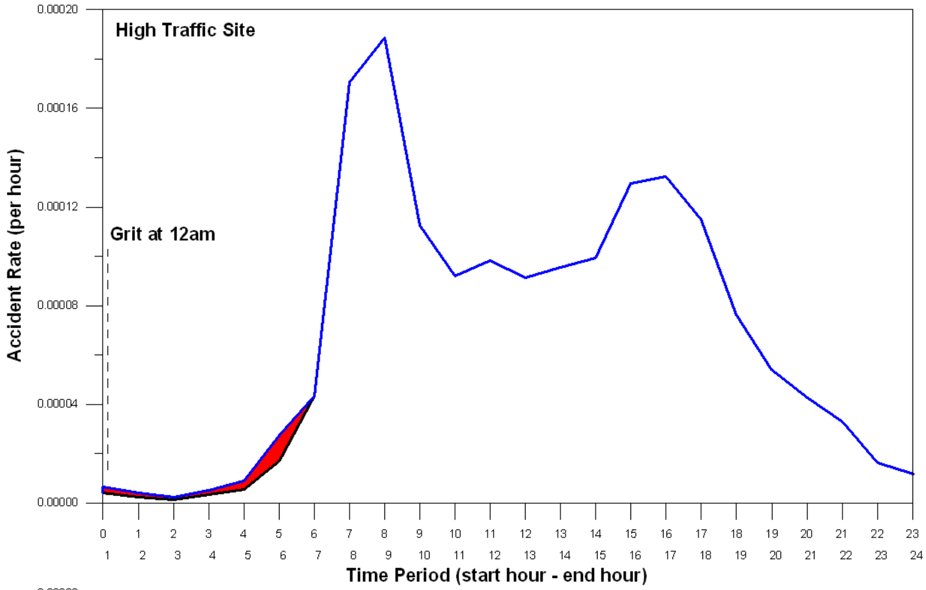

Low Traffic Site
Dewfall at 9pm
Accident Rate (per hour)
0.00003
0.00002
0.00001
0.00000
Time Period (start hour - end hour)

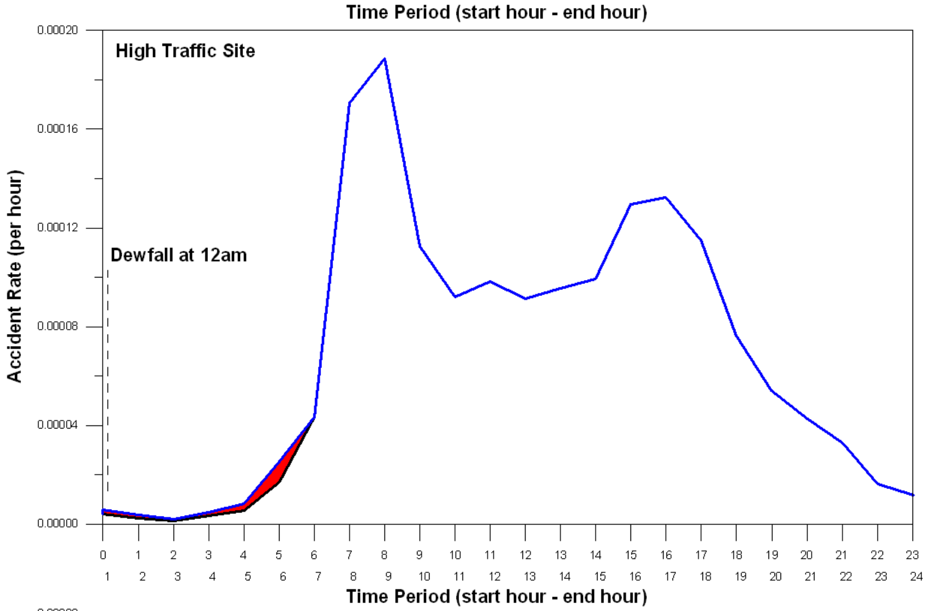

Low Traffic Site
Ice at 9pm
Accident Rate (per hour)
0.00003
0.00002
0.00001
0.00000
Time Period (start hour - end hour)

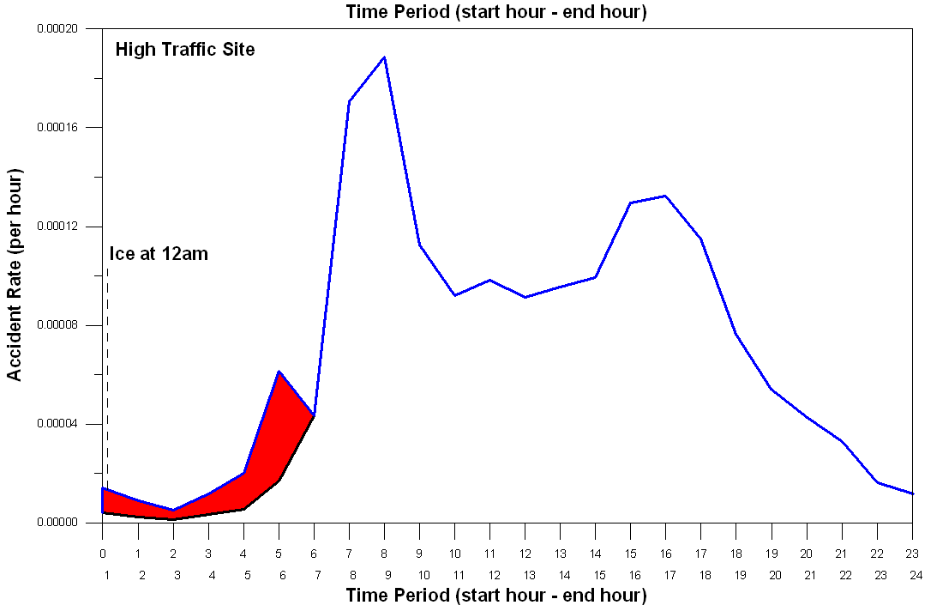
High traffic site – 12am



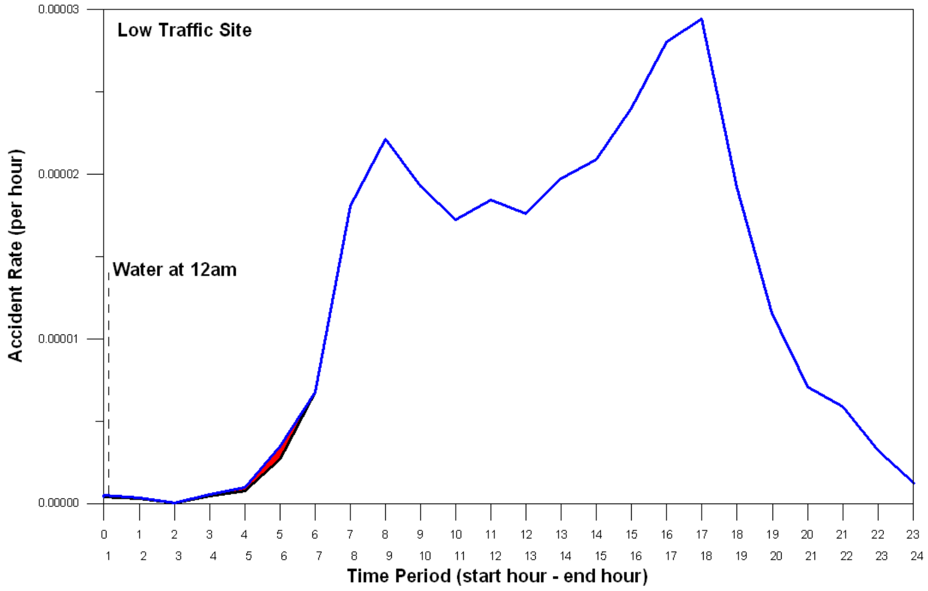


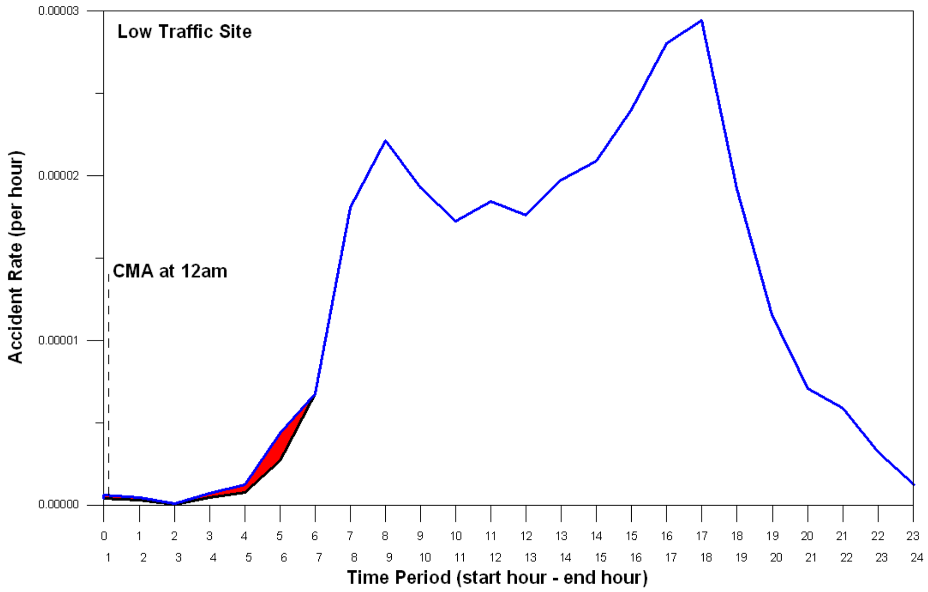

High Traffic Site
Grit at 12am
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

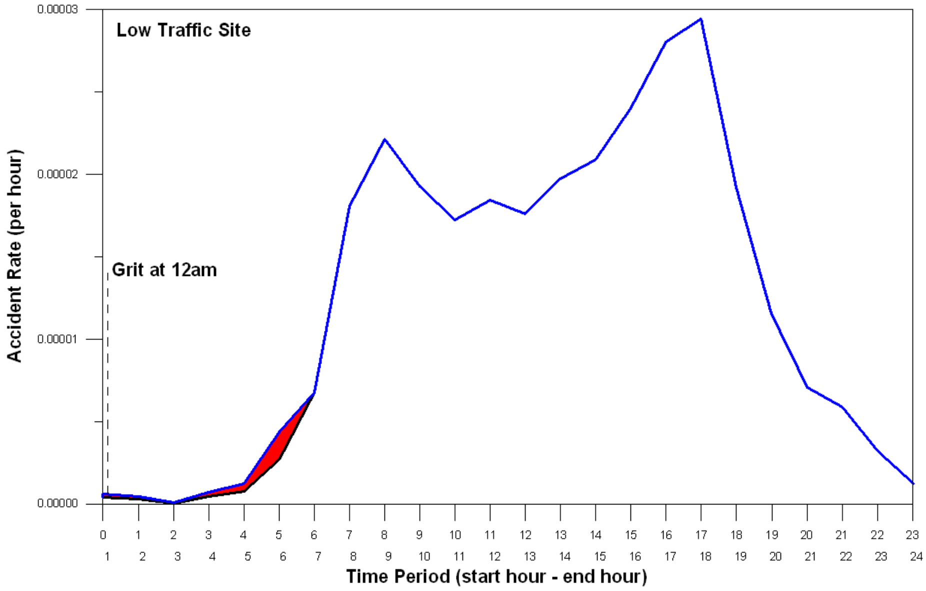

High Traffic Site
Dewfall at 12am
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

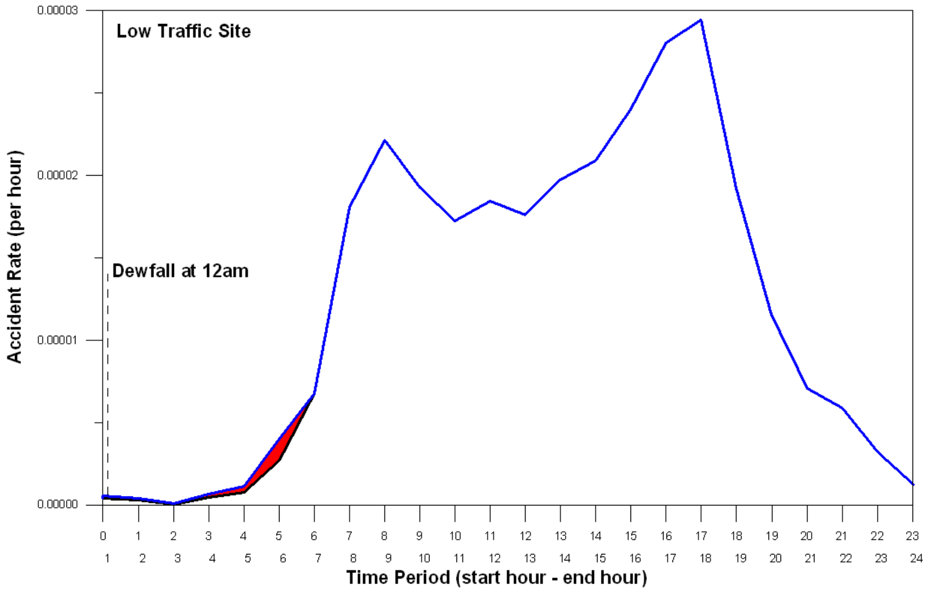

High Traffic Site
Ice at 12am
Accident Rate (per hour)
0.00000
0.00004
0.00008
0.00012
0.00016
0.00020
Time Period (start hour - end hour)

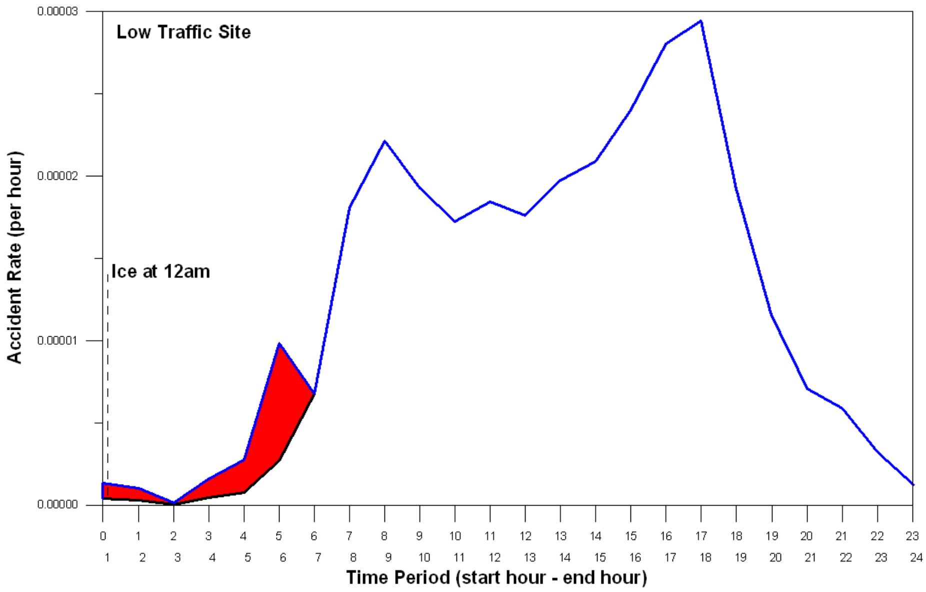
Low traffic site – 12am






Low Traffic Site
Grit at 12am
Accident Rate (per hour)
0.00003
0.00002
0.00001
0.00000
Time Period (start hour - end hour)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Low Traffic Site
Dewfall at 12am
Accident Rate (per hour)
0.00003
0.00002
0.00001
0.00000
Time Period (start hour - end hour)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


Low Traffic Site
Ice at 12am
Accident Rate (per hour)
0.00003
0.00002
0.00001
0.00000
Time Period (start hour - end hour)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24