

Evidential-based guidelines for temporary speed limits

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Abbreviations and acronyms

CoPTTM	Code of practice for temporary traffic management, 3rd ed. Transit NZ, Wellington
Df	Degrees of freedom
E	Number of equipment in work area
HCM	Highway capacity manual, TRB, Washington DC
N	Number of workers in active work area
NCHRP	National Cooperative Highway Research Program
NZTA	NZ Transport Agency
p	Distance between active work area and open lane
SD	Standard deviation
TSL	Temporary speed limit
TIRTL	The infrared traffic logger
TRB	Transportation Research Board, Washington DC
V_a	Speed reduction due to all other factors
V_f	Free travelling speed
V_{lc}	Speed reduction due to lateral clearance
V_{lt}	Long-term speed reduction
V_{lw}	Speed reduction due to lane width
V_o	Operating speed

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Executive summary

The aim of the research was to provide empirical evidence regarding the setting of temporary speed limits (TSL) around road works. To gain a fuller understanding of the factors influencing driver speeds the project combined traffic engineering and traffic psychology. This combination enabled an examination of both the **driver's** environment and the characteristics of individual drivers. Environmental factors included work site layout, road surface condition, and level of activity at a site, while driver factors included age and gender, as well as subjective risk perceptions and attitudes to speeding.

Eight sites with road works in the Wellington and Wairarapa regions were chosen, split by site visibility and posted TSL. Site visibility was divided into two conditions: continuous visibility (where the site was predominantly a straight road), and non-continuous visibility (where the site had a horizontal or vertical curve impairing visibility). The posted TSLs used were 70, 50 and 30km/h for 100km/h roads, and 30km/h for 50km/h roads.

Vehicle speeds were collected at two locations per site, on the approach to the site and at the beginning of the taper for the site. **Headway data was also collected at each site's taper**, and was used to determine whether the vehicle was free travelling or not (free travelling was defined as having a headway of 6s or greater). From each site 100 drivers were selected and sent surveys covering speed estimates, attitudes to road works and driving speed, as well as subjective risk perceptions regarding work sites in general and two specific work sites.

The setting of TSLs is based on two site-specific speeds: the site operating speed and the site maximum safe speed. The operating speed is the 85th percentile speed of free-travelling vehicles. The maximum safe speed is the upper limit of safe speeds based on the prevailing conditions (eg a specific stretch of road will have a different maximum safe speed if the road is wet compared to when it is dry). The TSL should be set so that the operating speed is equal to or less than the maximum safe speed.

The engineering investigation analysed vehicle speeds at work zones in order to establish whether the operating speed and the TSL were in reasonable accord. A methodology was developed to estimate TSL at work zones. If the maximum safe speed is less than the operating speed then the traffic management plan should be re-designed to suit the maximum safe speed. If the operating speed is significantly less than the safe speed then the TSL should be increased to a safe level of speed for several reasons (eg improve safety, increase **network efficiency**, **reduce driver's mistrust of speed limit signs**).

The psychological analysis examined drivers' speed choice behaviours in relation to their expressed attitudes. The purpose of this examination was to determine whether drivers' self-reports of attitudes and risk perceptions provided useful information for developing interventions to reduce driver speeds through work zones. For instance, did the perception of specific work zone risks relate to lower speeds, and if so, interventions could focus on making these risks more salient to drivers.

New Zealand work zone speed assessment

The initial assessment of speed variance at New Zealand work zones should help to answer the following question: are we able to find the reason behind tendencies to commit speed violations at work zones, or should we accept drivers' decisions regarding their speed choice at work zones?

The speed distribution data at the approach to and point of entry at each work zone showed that:

- the 85th percentile speed was considerably higher than the TSL for most sites
- the speed variance increased at the entry point, compared with the approach speeds, for most sites.

The literature review showed that the crash rate was low at sites where there was a reduction in mean speed and the percentage increase in speed variance was low, while sites with the characteristics observed for this study had a higher crash risk. It is important to consider reducing the mean and variance of speeds, including reducing the operating speed below the safe speed at work zones in the future. To achieve this, a guide should be developed for TSL estimation procedure at work zones in New Zealand.

Assessment of work zone speed prediction model

The model worked effectively in the model assessment, but accuracy could be improved with further research at a greater variety of sites. The following conclusions were drawn from our model assessment.

- 1 The estimated speed from the model was approximately equal to the measured operating speed at most of the sites except one. However, this site had specific characteristics that were not accounted for in the model (eg excessive dust).
- 2 In two out of eight sites the estimated speed was less than the measured speed. These two sites were influenced by other factors which were not appropriately considered in the model.
- 3 There were no sites at which the estimated speed was substantially less than the measured speed.

Taking the above three points into consideration, the model can be used to estimate the operating speed for the work zone site-specific plan assessment. This will help to identify any need for site safety improvement or traffic management plan improvements for determining TSLs. When considering the difference between the operating speed and existing TSLs from all eight sites, the accuracy of the prediction of site operating speeds was sufficient to improve TSL estimation in the future, although the model would benefit from improvement through future research. The model will help to identify any deficiencies in temporary traffic management plans or site design by determining a reasonable TSL.

Psychological analysis

The main analysis of the driver survey consisted of examining correlations between speed and attitudes to road work and the **respondents'** estimated and actual site approach and entry speeds. The general findings of these analyses were that road works and attitudes to speeding were more strongly correlated **with the respondents' speed estimates than with their actual observed speeds**. There was also no consistent effect of risk perception for observed speeds, which **indicated that drivers' subjective** perceptions had no measurable effect on their driving speeds.

Recommendations

Drivers do slow when entering work zones, but it is necessary to design work sites to reduce driver speeds further or to be safer with higher operating speeds. The predictive model is adequate for estimating driver speeds, but further testing would improve the accuracy of the estimates.

When determining a TSL the main factors to consider are the structural elements of the site and how these elements relate to driver speeds. Drivers' subjective risk perceptions do not appear to influence their actual behaviours, only their estimates of their own behaviours. The environmental factors which influence driver speeds therefore need to be determined through measuring actual behaviour. Simply measuring subjective perceptions is unlikely to provide information useful for developing speed-reducing countermeasures.

Abstract

A study was conducted to examine whether the New Zealand *Code of practice for temporary traffic management* guidelines for the implementation of temporary speed limits (TSL) result in driver speeds that match safe travelling speeds. Site approach and site entry speed data was collected at eight sites around Wellington, New Zealand, where TSLs were in place. Four TSLs (100 to 70km/h, 100 to 50km/h, 100 to 30km/h and 50 to 30km/h) and two visibility conditions (continuous and non-continuous) were used. Surveys were sent to 100 drivers at each site asking about their risk perceptions and attitudes to speeding and road works. While drivers did reduce speed from the approach to entry of a road works site, the reduced speeds, both the mean speeds and 85th percentile, were higher than the TSL. These findings indicate that improvements are needed regarding site design and TSL estimation to reduce the accident risk. Drivers' **subjective** risk perceptions, either site specific or general, were not related to their site entry speeds. Drivers also tended to underestimate the speed at which they would drive through a site. The survey results suggest that drivers' subjective perceptions do not influence their objective behaviours. Recommendations are made for improving the setting of TSLs based on estimates of driver speeds.

1 Introduction

The aim of the research was to minimise the number of crashes at work zones. Crashes occur from the interaction of vehicles, the environment and driver factors. To account for all three factors this research drew upon both traffic engineering and traffic psychology. Driver factors were considered in order to achieve maximum benefit from traffic engineering projects. The observed driver behaviour was speed **selection, with the subjective measures consisting of drivers' attitudes to speeding** and road works, and their perceptions of risk around road works (both site specific and in general).

The research investigated engineering and driver psychology issues related to speed reduction at work zones in order to prepare guidelines for estimating site-specific temporary speed limits (TSL). The engineering investigation and analysis assessed vehicle speeds at work zones in order to establish whether the operating speed and speed limits were approximately equal. Where there was an inadequate level of safety at a work zone site, a methodology was developed to estimate a suitable TSL for that site. Developing the methodology consisted of two main parts: safe-speed estimation and operating-speed estimation according to the site-specific plan. For a given site, if the safe speed is less than the operating speed then the site-specific plan needs to be re-designed to reduce the operating speed to the safe speed. If the design speed (ie intended speed at the work zone) is significantly less than the safe speed then the TSL needs to be increased to the level of safe speed for several reasons (eg to improve safety, **network efficiency, reduce drivers' mistrust of speed limit signs**). Please note that these are general requirements; no sites were redesigned for this project.

Literature reviews for the engineering and psychology elements were conducted and are discussed in chapter 2. The method used to estimate the operating speed at the approach to the work zone is discussed in chapter 3 and the method of estimating the operating speed at entry is discussed in chapter 4. Chapter 5 discusses the work zone data collection. Chapter 6 contains the engineering and psychological analysis. Procedures for estimating safe speed and the TSL are discussed in chapter 7. An overall discussion, including areas for possible future research, is given in chapter 8.

The recommended speed for work zones given in the *Code of practice for temporary traffic management* (CoPTTM) (Transit NZ 2004) is 20 or 30km/h less than the posted speed limit for the surrounding road. This reduction is slightly greater than the appropriate design speed variation in normal road sections where there are long sections and drivers are expected to vary their speed by 10km/h. The risks on normal sections of road differ from the risks in work zones. Different types of work require different safety levels and therefore lower speed limits may be appropriate for some work zones.

Our research tested the speed reduction performance using eight work zone sites where speed limits had been designed according to the most recent CoPTTM. The differences found between work zone speed limits and driver performance formed the basis for the proposed guidelines for estimating TSL. The guidelines include a procedure guide for testing the temporary traffic management plan. If the plan does not provide suitable site safety, then the procedure in the guidelines will propose improvements to the traffic management plan.

Ideally, the speed at which drivers choose to travel should match the intended design speed of the road and be in agreement with the road environment. However, in reality this does not always happen. Research and opinion demonstrate that driver speed is related to engineering, driver behaviour, education, driver irritation and enforcement. Work zone environments are no exception to this concept. Where actual speeds exceed proposed work zone speeds, unexpected costs arise in managing the work zone (eg policing, intelligent transportation system). Austroads (2003) noted that for a low crash rate the environmental speed should not change much along the highway. Transit NZ (2003) noted that 'The

design speed of successive geometric elements should not differ by more than 10km/h, where the drivers are expected to vary their speed as they travel along a section of road'. If the design speed changes in excess of 10km/h, the level of risk will be increased. Again, this is also applicable to work zones.

There are some circumstances in which the existing speed limit will be insufficient to improve the work zone safety in existing traffic management plans. In such situations, TSLs will minimise risk in temporary road infrastructure at work zones. However, it is not appropriate to reduce speed limits to compensate for risk created by an inappropriate work plan. It may instead be necessary to consider alternative work plans to minimise risk without disrupting traffic flow. Where options are limited by proximity to a work zone environment, a reduction in the speed limit should be considered.

To determine the TSL, consideration should be given to the safety of road users and site workers, and the potential damage to road structure (including the road surface). The TSL should be less than or equal to the maximum safe speed. The maximum safe speed depends on the type of work (eg resurfacing), what pedestrian or vehicle activity is present and the characteristics of the road, etc. The speed limit should encourage a uniform speed and allow sufficient reaction time for drivers to respond to unusual events or directions from the manual traffic controller at the work site. The TSL must be realistic or it will often be ignored, resulting in increased risk at the work zone. Therefore temporary speeds need to be suitable for the environmental conditions.

Leonard (2007) noted from his study, **that** 'individuals indicate that the presence of warnings that are not accompanied by the hazardous situations that would be expected can dilute the influence of the warnings'. Drivers often assess risks in a potentially hazardous situation by looking for the presence of workers or activities. If there are no workers visible then drivers may believe that the work has been completed but that the signage has not been removed (eg Leonard 2007). This belief can be incorrect. For instance, the TSL may have been estimated from risk factors not salient to drivers, work may have been postponed due to construction-related difficulties, or changes in the site situation may have made judging risk problematic. The difficulty in determining the difference between completed sites where signage has not been removed and uncompleted sites creates confusion for drivers. It is therefore important to ensure that signage is removed once the work has been completed.

2 Literature review

2.1 Traffic engineering

The Michigan Department of Transportation (1996) reported that:

Many believe worker safety is improved when low speeds are posted. However, most motorists drive at a speed they feel is reasonable. If motorists do not believe the posted speed is reasonable, they usually do not comply and worker safety is compromised. (p2)

It further suggested that:

*National studies indicate speed reductions should not exceed 10 mph. If a lower speed is required, **the speed limits should be stepped down in 10 mph increments...Set work zone speed limits no more than 10 mph below the existing speed limit of 65 mph prior to the work zone, except when extreme conditions warrant a lower speed.** (p2)*

This was because the engineering operations committee did not accept that lower speed limits improved worker safety. They also noted that worker safety could be improved by safety barriers. However, fully protective barriers (eg concrete barrier) are generally not used in short-term work zones, and concrete safety barriers are not always a perfect solution for vehicle safety. Installation and removal of safety barriers (eg concrete barriers) for a short period is not effective in terms of cost, time and traffic disturbance. This option really depends on the optimum solution by considering cost and safety of workers and road users.

Some types of plastic barriers, called guiding barriers, which are of very similar shape to concrete barriers, are also used in work zones. The mobilising and demobilising cost for these types of non-concrete barriers is cheaper than the concrete barriers. These guiding barriers are normally used at high-volume roads for temporary work sites but they are less effective at preventing vehicles entering a work site than concrete safety barriers.

Kuennen (2007) noted National Institute of Occupational Safety and Health data for 2005 says that while motorists think workers are at the most risk, in reality, the motorists themselves are the victims in four out of every five work zone fatalities. This international data indicates the need for improvement in motorist safety at work zones and indirectly indicates that motorists do not always assess risk accurately at work zones.

Bai and Li (2006) analysed US crash data and identified risk factors related to work zone crashes. Four of these factors are listed below:

- 1 Around 60% of crashes were on the rural two lane highways with speed limits from 82 to 112km/h, and around 50% of crashes were at 'complex geometric alignments'.
- 2 68% of multi-vehicle crashes were head on, angle-side impact and rear end, with about 40% of multi-vehicle crashes being caused by heavy trucks.
- 3 'Human errors, including inattentive driving and misjudgement or disregarding of traffic control were the top killers'.
- 4 'Inclement weather and the unfavourable road feature (interchange area, intersections, ramps, etc) do not significantly contribute to fatal crashes'.

The above points indicate that more efficient and effective traffic management devices and strict traffic law enforcement will reduce crashes. The report also noted that 'there is an urgent need to develop speed management methods that can be strictly enforced in the work zone area' (Bai and Li 2006). Future research should focus on speed management methods to reduce speeds to the TSL rather than expecting drivers to travel at the TSL.

Higher speeds allow less time for drivers to notice unexpected changes in the driving environment. NTUA (1998) indicated several reasons for lowering speed limits at work zones, the most important being.

- adjustment to reduced roadway standards: narrow lanes, deviations (eg to/from the reversible flow) or reduced shoulders are common and can cause crashes from running off the roadway
- protection of site workers
- unexpected queuing which can result in rear-end crashes if the speed is not reduced before reaching the hidden queues.

Warning signs are not always effective, and safe headway distances are not always maintained. Changes in driver behaviour are necessary to increase safety, and hence regulations are necessary (NTUA 1998). Typically, these regulations concern speed limits. The NTUA report noted that experimental studies show most drivers approach work zones well above the speed limit and do not reduce speed until just before there is a sudden change in road conditions, such as a lane crossover. Drivers then reduce their speed unexpectedly.

ARROWS (1998) recommended that TSL standards in European countries should be consistent in order to ensure a high level of safety. ARROWS (1998) noted that:

people are not willing to adjust their speed because they do not see the urgency to do so. Drivers should therefore acknowledge the increased risk: not only because workers are present but also because of narrowed lanes, sudden curves, etc.

The report demonstrated how sudden braking or speeding within work zones is dangerous. Work zone environments are less predictable than other normal traffic situations due to slow merging vehicles, congestion, sudden curves, sudden braking and poor visibility caused by heavy vehicle movement or dust. Most people are more careful when entering driveways or main stream traffic than when entering a work zone where a similar level of risk is present.

The CoPTTM noted that the:

speed limit should not exceed the maximum safe travel speed, which depends on the degree of pedestrian and vehicle activity, the type and extent of the work in progress and the characteristics of the road.

A procedure to estimate the maximum safe travel speed is not given in the CoPTTM. The manual encourages uniform speeds and notes that TSLs should be set to enable drivers to maintain control if any unusual events occur or direction is given from a manual traffic controller. The recommendations in table 2.1 are listed in the manual:

Table 2.1 Recommended temporary speed limit according to the site condition (extracted from the CoPTTM)

Situation	Recommended temporary speed limit
Where traffic has to traverse the actual active work site	30km/h
The approach to a two-way one-lane operation, eg manual traffic controllers or portable traffic signals	30km/h
Protection of a new seal	50km/h
New seal, swept but not marked	70km/h
Work site activities protected by a barrier system	No temporary restriction

Note: These temporary speed limits are recommended where the original speed limit was equal to or greater than the those shown.

Additionally, the CoPTTM states:

*TSLs of less than 70 km/h in areas with permanent posted speed limits of 100 km/h, or less than 50 km/h in areas with a permanent posted speed limit of 70 or 80 km/h shall not be used without **additional “Positive Traffic Management” measures** (section C 4.4).*

Positive traffic management measures include manual traffic controllers, traffic lights and narrowing lanes (CoPTTM, section C10).

Chute (2004) provided revised guidance for TSLs at road works on high-speed roads, stating that ‘In general a speed limit should not be introduced where the length restriction would be less than 800 metres’ (p5). This recommendation is not justified because the only difference in the safety risk between shorter and longer sites is the exposure risk. He noted that ‘Generally for motorway and dual carriageway normally subjected to the national speed limit a temporary maximum speed limit should not be less than 40mph and for other high speed road less than 30mph’. These speed limits are also not justified as they are not low enough to ensure safety for certain work zones. In these two cases, the term ‘generally’ implies that Chute allowed for exceptions. Taylor et al (2000) noted a 5km/h speed reduction from these speed limits created significant crash reductions at a section with no road works. ARROWS (1998) reported that ‘more than half the accidents in work zone areas on motorways are rear end collisions (eg 60% in the UK, 63% in Germany)’. It is also common for night-time crashes to be associated with inappropriate vehicle speeds. These results show **Chute’s** temporary speed estimation procedure should be revised in **the future to encompass greater focus on speed control rather than selecting the driver’s chosen speed.**

NCHRP (1996) recommended a procedure for estimating work zone speed limits based on four steps:

- 1 Determine the existing speed limit
- 2 Determine which work zone condition applies
- 3 Determine which factors for the appropriate condition apply to the specific site
- 4 Select the work zone speed limit reduction.

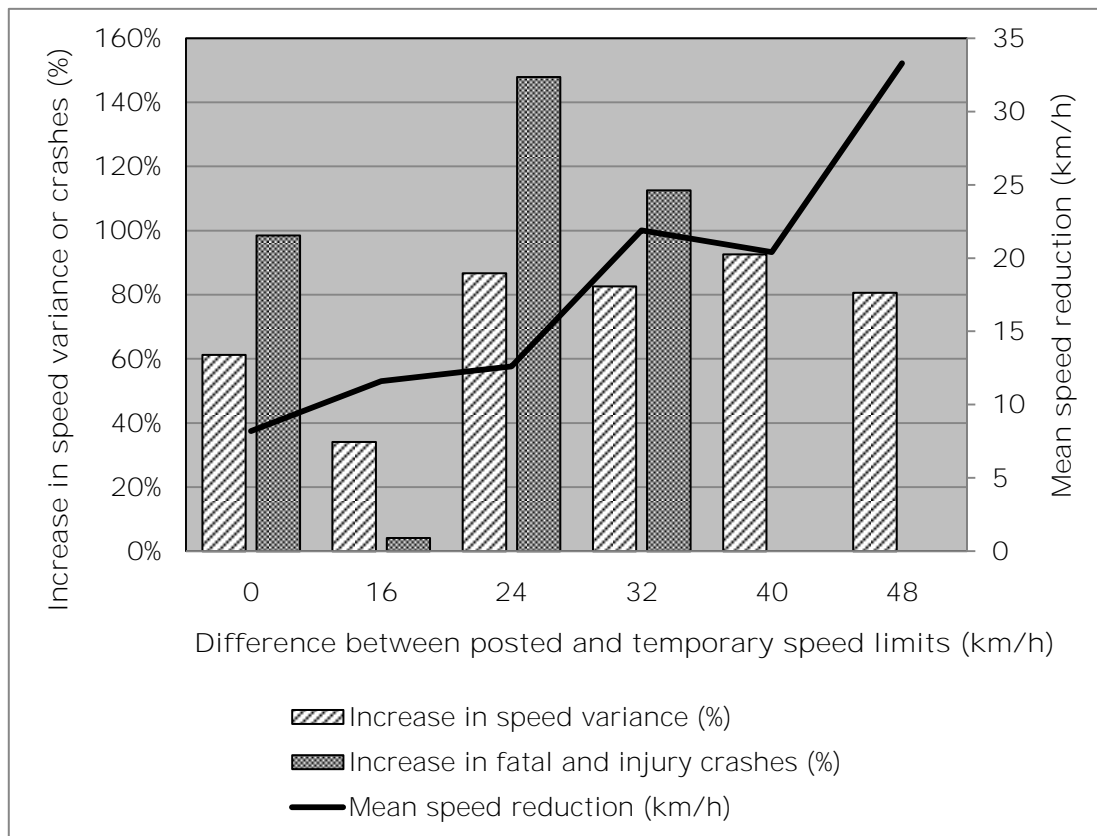
In general, maximum speed reduction will be imposed by 10mph (16km/h). This procedure was assessed and results were noted in Migletz et al (1999).

Migletz et al (1999) presented the data from an assessment of a procedure to determine work zone speed limits. This data has been extracted and plotted in figure 2.1.

Figure 2.1 shows that even when there was no TSL in place mean speeds still reduced by 5 to 10km/h. The percentage increase in speed variance indicated a wider spread of driver speeds, and this increase was

related to an increase in fatal and injury crashes. The relationship between speed variance and crashes raises the question: is it better to increase the speeds of those drivers who travel at less than the mean speed, or to slow the speeds of drivers who travel faster than the mean. When considering safety we need to reduce the mean by controlling the speeding drivers rather than controlling the slower drivers. If we set a lower TSL we are encouraging drivers to slow down, but if we set a higher TSL we are encouraging drivers to speed which has negative safety implications (see also Frith and Patterson (2001) for general roads).

Figure 2.1 Summary of mean speed reduction, the percentage increase in speed variance, and the percentage increase in crashes for different speed limit reductions (data extracted from Migletz et al (1999))



Rear-end accidents at work sites are common. These generally occur because drivers are forced to reduce speed, causing queues or congestion, combined with drivers who drive too fast for the conditions and cannot react or stop within the necessary time. Preventative options include designing sections to reduce congestion or forcing the fast driver to slow down. In situations such as work zone-related crashes (eg rear-end crashes), the speed variance and mean analysed together will provide more relevant information than mean speed alone. Solomon (1964) noted that crash risk was higher for slower drivers than for those driving at mean speed. In his research, crashes, including rear-end and angle collisions, were related to driver speeds lower than the driver would chose in free-travelling conditions. However, driver speeds may have been restricted by the number of intersections or congestion (Frith and Patterson 2001). Hence, we cannot conclude that high crash-risk areas are created by slow drivers under free-travelling conditions. Solomon analysed the number of people injured per 100 crash-involved vehicles by vehicle speed. This analysis demonstrated that the number of people injured per 100 crash-involved vehicles was positively related to vehicle speed, indicating that controlling speeding drivers will help to reduce crash severity.

Every 1.6km/h drop in mean speed can produce up to a 5% percent reduction in fatal crashes (Taylor 2000). The greatest reduction in casualties would come from reducing the speed of the faster drivers (Taylor et al 2000). It should be noted that if the percentage increase in speed variance can be reduced then the percentage increase in crashes (Migletz et al 1999) will also reduce. In the New Zealand roading context, the aim is to reduce the percentage increases in fatal and injury crashes to significantly less than 4.1% (see figure 2.1: 4.1% at 16km/h speed limit reduction). To achieve this, our speed limit reduction can be above 16km/h, depending on the site condition.

Figure 2.1 shows that for TSL-controlled sites the percentage increase in speed variance from upstream to work zone is lowest when the speed limit reduction is 16km/h. This could be one of the contributors to a smaller percentage increase in fatal and injury crash rates during construction projects compared with before the project. It should be noted that a reduction in speed inconsistencies is highly influential in reducing the percentage of crashes. In general, when the 'individual who drives at a speed more than about 10–15 percent above the average speed of the traffic around them, the likelihood of their being involved in a crash increases significantly' (Maycock et al 1998; Quimby et al 1999a, b) noted by (Taylor et al 2000). So it is important to reduce the speed mean and variance at work zones by reducing the speeds of the faster drivers.

There is a tendency for an increase in crash rates when speed variances or speed limit reductions increase. This does not mean that the slower vehicle has more chance of accidents as previously mentioned. At work sites, drivers may react to the construction activity and slow down even though the road is clear and we need to expect the driver following behind to be able to slow down in a safe manner without causing a rear-end crash. Targeting speed variance is not a very good method to reduce crashes (Zaal 1994) and forcing the slower driver to speed up is also not a good approach towards reducing crashes in the work zone.

No matter what causes a crash, it is the driver's speed which directly affects the force of an impact. Lower impact speeds greatly reduce the crash risk and severity of injury. In a literature review, Arampamoorthy (2005) discussed in detail the impact on crash frequency and severity by traffic mean speed and speed variance, showing the reduction in death and injuries that could be achieved. Additionally, crashes may be clustered at places where the speed variance or mean speed is high. From national and international literature there is overwhelming evidence that lower speeds result in fewer collisions of lower severity (Fildes and Lee 1993; Finch et al 1994; Taylor et al 2000; TRB 1998).

Crash liability is predicted by self-reported tendency to commit violations, such as exceeding the posted speed limit but not by a tendency to make errors and lapses (Parker et al 1995). Violations are deliberate contraventions of safe driving practice, while errors are typically misjudgements and failures of observation that may be hazardous to others. Stradling (1999) proposed that speed violations reduced safety margins so there was less room or time to correct errors. The question is can we find a way to reduce the likelihood of speed violations, or do we accept the decision of some drivers to speed at work zones? If we are going to **accept the driver's choice then we may not be able to reduce the work zone-**related increases in fatal and injury crashes. For a maximum reduction of crashes at work zones we need to find innovative solutions to reducing speed variance at work zones, regardless of the safe speed. The optimum solution will both improve the safe speed by improving site design and find answers to reducing speed variance by minimising the number of speeding drivers at work zones to such a level that the mean speed is acceptable for the type of site.

It is generally accepted that narrowing lane width, shoulder width or changing cone spacing along the approach will increase speed reductions at work zones (eg CoPTTM, section C10). Heimbach et al (1983) studied the operating speed and crashes on four-lane urban undivided arterials and found that when the

lane width decreased, the operating speed decreased but the number of crashes increased. Perhaps this can be explained by considering whether design standards reduce as the lane width reduces. Kemper et al (1984) studied the effect of narrow lanes in construction sites and found 9ft lanes in the early stage of construction caused slower speeds but increased crash rates, although there were fewer injury crashes. The study was conducted at a bridge deck reconstruction site. The available recovery area (ie seal shoulder and lateral clear distance) may be limited at this site. It appears narrowing the lane could help to reduce the mean speed but it has a negative effect on the number of crashes if the recovery area is limited. It appears that lane and shoulder width combined has the most important impact on risk, and that decreasing seal width will result in an increase in risk (Austroads 2010).

Chitturi et al (2005) studied the effect of narrow lanes and lateral clearances on the speed of cars and heavy vehicles in 11 work zones on interstate highways in Illinois, US. Speed reduction values in work zones were greater than the speed reduction values in regular freeway sections. They recommended speed reduction for work zones of 16.09, 11.27, 7.08 and 3.38km/h for lane widths of 3.05, 3.2, 3.35 and 3.51m respectively, which are significantly different from the *Highway capacity manual* (HCM) (TRB 2000) suggested values for basic freeways in the US. The two environments themselves are clearly different (eg no work activity compared to temporary traffic management), posing different risks and planning issues, so differences in speed reductions are to be expected. Benekohal et al (2004) developed a model for estimating operation speed at work zones which is discussed later. They recommended the use of the values in the HCM for speed reductions caused by lane width and lateral clearance.

Benekohal et al's (2004) study chose a site later used in Chitturi et al (2005) and found that one site with intense work activity 0.3m away from travel lane width of 3.7m had a speed reduction of 17.7km/h.

Chitturi et al's (2005) study found a speed reduction of 9.01km/h caused purely by a lack of shoulder (ie no lateral clearance) on either side of the road for the same lane width of 3.7m. These two studies indicate that work intensity and lateral clearance have a combined effect on speed reduction which increases with the lane width effect.

Zhao and Garber's (2001) study concluded that work zone crashes occurred predominantly in the activity area and there was a higher rate of multi-vehicle crashes in work zone locations compared with non-work zone locations. The location of work intensity possibly influenced crash risk which could be related to driver distraction, speed reduction or construction-related heavy vehicle involvement.

Taylor et al (2005) developed a simplified Excel spreadsheet to estimate speed profile along work zones followed by an artificial neural network speed-profile model. This research was limited to two work zone types: lane closure and median crossovers. The following variables were used for the input:

- work zone type: lane closure and median crossover
- work zone location: taper, within work zone
- length: distance from beginning of work zone (measured from the lane taper)
- radius of horizontal curve
- posted speed limit
- roadway type: permanent, temporary
- slope: flat, upgrade, down grade, crest curve, sag curve
- travelled way width
- right shoulder width

- left shoulder width
- total paved width
- roadside device on right (none, drum, vertical panel, other soft, guardrail, barrier, opposing traffic with no separation)
- offset from travelled way of roadside device on right
- speed upstream from advanced warning area
- previous measured or predicted speed
- distance from previous measured or predicted speed.

The results indicated that predicted and expected profiles were very similar. This model was limited to two types of work zones, with modifications required for other types of work zones. In our research we focused on determining the speed at the start of work zones. Most of the variables were considered to estimate the speed reduction at work zones using a simplified model.

Benekahal et al (2004) developed a simple model for predicting the work zone operating speed for two lane highways and this was selected for assessment. The model is explained in detail in chapter 4. The 85th percentile speed was influenced by the work zone configuration (eg single lane closure, median cross over) type of road way infrastructure (eg permanent or temporary), work zone location (eg within the lane taper or downstream distance travel from lane taper of the beginning of the work zone), posted speed limit, vertical alignment (eg crest curve) and total paved cross section width. The Benekahal model was simplified and included other different variables, such as the number of people working in the zone and the amount of heavy machinery on site.

Harb et al (2008) noted that road geometry was a significant risk factor associated with single vehicle crashes in freeway work zones. They noted there was an increased probability of crashes on straight level roads compared with straight up/down grade roads, level curve roads, or up/down grade curve roads. Regardless of whether the site was fully or partially visible, the straight level roadwork zones were significantly affected. A study by Daniel et al (2000) further proved that fatal work zone crashes were less influenced by horizontal and vertical alignment compared with non-work zone locations. This was because drivers might be more likely to drive cautiously on vertical and horizontal curves where there were work zones.

However, the initial assessment of speed variance at New Zealand work zones will help to answer the question noted previously: are drivers obeying the posted TSL? If not, what can be done to ensure driver speeds match the safe speed for a given site?

2.2 Traffic psychology

This section provides a brief overview of the psychological concepts that will be discussed in this report.

2.2.1 Risk perception and driver behaviours

An individual's risk perceptions are generally considered to influence their driving behaviours (Møller and Hels 2008). Perceptions of risk, and attitudes towards risk, are usually measured through self-report, while driving behaviours are measured either through self-report or observation. Studies using self-report measures of driving behaviour have generally found significant relationships between reported perceptions and behaviours (Iversen 2004; Machin and Sankey 2008; Ulleberg and Rundmo 2003).

However, limited relationships have been found when observed, rather than self-report, behaviours are **used. For instance, Farrand and McKenna (2001) found no significant relationships between participants'** self-reported risk perceptions, driving ability and accident likelihood, and their scores on a hazard-perception task, while the three self-report measures were significantly related to each other. Sümer et al (2007) compared self-reports of hazard perception with a hazard-perception task and found no significant relationship for novice drivers, and a significant negative relationship for experienced drivers. Sensation avoiders and sensation seekers have been shown to perceive the same level of risk in a car-following situation, even though the avoiders had longer following distances than the seekers (Heino et al 1996). Gregersen (1996) compared the self-reported and actual skills of learner drivers trained under one of two strategies: 'insight', making the driver aware of their limited abilities, and 'skill', practical training for the **drivers in how to better handle a skidding car. The skill group's estimate of their skill was higher** than that of the insight group, but their actual skill levels were the same.

2.2.2 Speed choice

Self-reported speeding behaviours have been shown to be related to self-reported risk estimates (Brown and Cotton 2003) and intentions to speed (Elliot and Armitage 2006; Letirand and Delhomme 2005). Attitudes towards speeding, self-reported speeds, and subjective norms regarding speeding, can be used to predict observed speeds (Åberg et al 1997; Haglund and Åberg 2000; Warner and Åberg 2006). For both Åberg et al (1997) and Warner and Åberg (2006) self-reported speeds were predicted more strongly than observed speeds, while for Haglund and Åberg (2000) this trend was reversed. Corbett (2001) also found a relationship between self-reported speeds and observed speeds, as well as finding that drivers travelling below the speed limit tended to overestimate their speeds while drivers travelling over the speed limit tended to underestimate speeds. It appears, then, that driver attitudes and perceptions regarding speeding are more predictive of actual speeds than their attitudes and perceptions towards risk.

One issue with using a single instance of observed speeds as a dependent variable is that driver behaviours may not be consistent (eg a driver exceeding the speed limit at one moment may not exceed it at another). Wasielewski (1984) found a correlation of 0.26 between repeated speed measurements, while Haglund and Åberg (2002) found correlations ranging from 0.49 to 0.81 for repeated measurements. These findings suggest that there is some consistency in driver speeds, but that using only one observed speed measurement is likely to increase error.

2.2.3 Implications

While driver attitudes towards speeding, and estimates of their own speed, are likely to relate to their observed speeds, it is less likely that their *subjective* risk perceptions will relate to their observed speeds. **This does not mean that a driver's risk perceptions do not affect their speed choice**, but rather that the factors that drivers subjectively perceive as affecting their speed differ from the factors that actually affect their speed. As much of the risk literature examines risk perceptions in general it is uncertain whether site-specific risk perceptions will relate to observed speeds.

3 Operating speed

In general, roads have a design speed that should consider driver expectations. The operating speed of a curve often exceeds the advisory speed of the curve (figure 2 in Tate and Turner (2007)). Designers need to consider the operating speed to minimise the risk.

Austrorads (2003) noted that the operating speed is 'the 85 percentile car speed at a time when the traffic volume is low'. The operating speed can be measured or, if the road is in the design stage, estimated. There are three basic elements which influence the operating speed; the driver, the vehicle and the environment. These elements are examined in more depth as road geometry (eg lane width, shoulder width, curve radius), road characteristics (eg grading, cross-section, surface condition), driver behaviour (eg acceleration in the straight portion and deceleration within curves various and acceleration or deceleration depend on clear view), environmental conditions (eg weather, light), vehicle (eg car speed is different from truck speed).

3.1 Operating speed at curve and straight

Austrorads (2003) provides two figures for acceleration on straights and deceleration on curves. Table 3.1 shows the operating speed and the curve radius relationship as given in Austrorads (2003).

Table 3.1 Curve radius and the operating speed relationship (extracted from Austrorads (2003))

Range of radii in section (m)	Single curve section radius (m)	Section operating speed (km/h)	Range of radii in section (m)	Single curve section radius (m)	Section operating speed (km/h)
45-65	55	50	180-285	235	84
50-70	60	52	200-310	260	86
55-75	65	54	225-335	280	89
60-85	70	56	245-360	305	91
70-90	80	58	270-390	330	93
75-100	85	60	295-415	355	96
80-105	95	62	320-445	385	98
85-115	100	64	350-475	410	100
90-125	110	66	370-500	440	103
100-140	120	68	400-530	465	105
105-150	130	71	425-560	490	106
110-170	140	73	450-585	520	107
120-190	160	75	480-610	545	108
130-215	175	77	500-640	570	109
145-240	190	79	530+	600	110
160-260	210	82			

Austrorads (2003) suggests considering the following when estimating operating speed:

- individual curves separated by a length longer than 200m of straight
- acceleration when vehicle speed is reduced below the section operating speed

- if a curve is followed by a lower operating speed curve, then acceleration will occur on the straight between the curves until the operating speed is reached. The rate of acceleration depends on the clear distance (see Austroads 2003). The acceleration ranging from 1km/h for every 30m to 1km/h for every 5m depends on the clear distance.

3.2 Effect of lane width

Austroads (2003) noted that if lane width is less than 3m then the speed will reduce by 3km/h. The CoPTTM sets the minimum lane width within a work site according to the speed limit using the guidelines presented in table 3.2.

Table3.2 Speed limit related to lane width at work zones (extracted from the CoPTTM)

Permanent/temporary speed limit	30km/h	50km/h	60km/h	70km/h	80km/h	100km/h
Minimum lane width	2.75m	3.00m	3.00m	3.25m	3.25m	3.50m

Lane width should not be greater than 4m. If the proportion of heavy vehicles is high, then the lane width may need to be greater than the width given in the table up to a maximum of 3.5m. Chitturi et al (2005) recommended speed reduction in work zones of 16.09, 11.27, 7.08 and 3.38km/h for lane widths of 3.05, 3.2, 3.35 and 3.51m respectively. The operating speeds estimated from these speed reduction values are much higher than the values in table 3.2, but they note that the estimated operating speed is not necessarily the safe speed. For instance, Heimbach et al (1983) reported that, for four-lane urban undivided arterials, as the lane width decreased operating speed also decreased but the number of accidents increased.

3.3 Effect of pavement condition

If the pavement surface is poor or broken then the speed will reduce by 5 to 10km/h (see further details in Austroads (2003)).

3.4 Operating speed of trucks

The speed of cars and trucks is the same on high-speed roads and flat terrain. Table 3.3 is given in Austroads (2003). Note that in New Zealand the maximum legal speed for trucks in 100km/h zones is 90km/h (NZTA 2009).

Table 3.3 Car and truck operating speed comparison (extracted from Austroads (2003))

Car speed (km/h)	110	100	90	80	70	60	50
Truck speed (km/h)	110*	100*	80	70	60	52	43

Note: On high-speed rural roads truck speeds equal car operating speeds.

3.5 Operating speed at grades

Austroads (2003) does not provide formulas for estimating the operating speed on grades but some details are available which can provide a basic estimate of operating speed. These relationships require simplification to facilitate easy estimation for work zone designers.

Table 3.4 A comparison of light and heavy vehicle speed reductions on hills (extracted from Austroads (2003))

Grade	Reduction in vehicle speed as compared to flat grade %				Road type suitability
	Uphill		Downhill		
	Light vehicle	Heavy vehicle	Light vehicle	Heavy vehicle	
0-3	Minimal	Minimal	Minimal	Minimal	For use on all roads
3-6	Minimal	Some reduction on high speed roads	Minimal	Minimal	For use on low-moderate speed roads (incl high traffic volume roads)
6-9	Largely unaffected	Significantly slower	Minimal	Minimal for straight alignment. Substantial for winding alignment	For use on roads in mountainous terrain. Usually need to provide auxiliary lanes if high traffic volumes
9-12	Slower	Much slower	Slower	Significantly slower for straight alignment. Much slower for winding alignment	Need to provide auxiliary lanes for moderate-high traffic volumes. Need to consider run-away vehicle facilities if proportion of commercial vehicles is high.
12-15	10-15km/h slower	15% max. Negotiable	10-15km/h slower	Extremely slow	Satisfactory on low volume roads (very few or no commercial vehicles)
15-33	Very slow	Not negotiable	Very slow	Not negotiable	Only to be used in extreme cases and be of short lengths (no commercial vehicles)

Using this data the approach speed to the work zones can be estimated. Further details for estimating the operating speed can be found in Austroads (2003).

3.6 Operating speed at work zones

The operating speed within a work zone differs from the operating speed on the approach to a work zone. The operating speed within the work zone is dependent on a variety of factors including work intensity, lane width and lateral clearance (see chapter 4 for a full list from Benekohal et al (2004)). However, it is not possible to develop a suitable relationship between all the influencing factors based on current research. The relationship we propose using is discussed in chapter 4.

4 Factors influencing work zone speed

To determine a suitable TSL, consideration should be given to the safety of road users and site workers as well as to the damage done to the work surface (NCHRP 1996). The TSL should not exceed the maximum safe travel speed for the prevailing conditions of the work zone. The maximum safe speed depends on the type of work, who the road users are, vehicle activities, adjoining land users, and the characteristics of the road. If the speed limit is set unreasonably low then drivers ignore it (eg Goldenbeld and van Schagen 2007). An unreasonably low TSL in a work zone may result in major backups upstream of the zone and increase the risk for certain types of crashes. The TSL should encourage a uniform speed while being low enough to allow the driver to react to any unusual events occurring, or to respond to instruction from a manual traffic controller at the work site.

Vehicle operating speed at a work zone depends on approach speeds to the work zone (ie the free-travelling speed just before the work zone) and speed reduction factors within the work zone. The approach speed can be estimated from the guidelines in Austroads (2003).

The approach free-travelling speed estimation is based on the following factors:

- road alignment (eg length of the straight road section, series of curves, or both)
- road characteristic (eg the gradient, cross section or surface conditions)
- vehicle characteristic (eg proportion of cars and trucks).

There are several other factors governing operating speed such as surface friction, curvature, weather conditions, and pedestrian or vehicle activity. However, there is insufficient knowledge about these factors to accurately understand or estimate their impact.

Speed reduction factors within the work zone can be estimated from the following elements (Benekohal et al 2004):

- work intensity
- lane width
- lateral clearance
- other factors:
 - surface condition
 - traffic flow breakdown
 - weather conditions
 - local environmental condition at work zone (dust, noise, distraction due to work activities etc)
 - layout of the work zone
 - inflow and out flow of vehicles.

Work intensity is determined from the number of workers, the amount of equipment, and the distance between the working area and the closest open traffic lane. This distance is related to the lateral safety zone defined in the CoPTTM. In relation to low-volume roads (less than 500 vehicles per day) the code notes that ‘A full width lateral safety zone should be provided but this may sometimes be impractical because of road environment restrictions. In this situation the lateral safety zone width may be reduced and, in some cases, a lateral safety zone will not be able to be provided’. In certain cases concrete barriers

are used to minimise the lateral safety zone, but only when it is a long-term site. Cone delineation is used for short-term sites. The lateral distance is based on the type of barrier used in the lateral safety zone; therefore the work intensity ratio is governed by the type of barriers in the lateral safety zone.

The following relationship was proposed by Benekahal et al (2004).

$$V_o = V_f - V_{lw} - V_{lc} - V_a - V_{st \text{ or } lt} \quad (\text{Equation 4.1})$$

Where

V_o operating speed (mph)

V_f free-travelling speed (it was assumed that V_f = speed limit + 5mph or estimated speed)

V_{lw} speed reduction due to lane width based on the HCM (TRB 2000)

V_{lc} speed reduction due to lateral clearance based on HCM (TRB 2000)

V_a speed reduction due to all other factors (if no information available then this factor should not apply)

$$V_{st} = 11.918 + 2.6766 \ln(W_{lr}) \text{ for short-term speed reduction} \quad (\text{Equation 4.2})$$

$$V_{lt} = 2.6625 + 1.2056 \ln(W_{lr}) \text{ for long-term speed reduction} \quad (\text{Equation 4.3})$$

$$W_{lr} = (N+E) / p \quad (\text{Equation 4.4})$$

Where

W_{lr} work intensity ratio

N the number of workers in active work area (varies from 0 to maximum 10)

E the amount of equipment in work area (varies from 0 to maximum 5)

P the distance between the active work area and open lane (varies from 0.3048m to a maximum of 2.7432m; 1ft to 9ft)

Long-term speed reduction measures (eg using concrete barriers) are different from short-term speed reduction measures (eg using cones). Two different equations (equations 4.2 and 4.3) are noted above to calculate the speed reductions related to the duration of work and the type of barrier used in a lateral safety zone.

The above model was developed and calibrated for US highways and requires testing in the New Zealand environment. Work zone speed survey data and site data collected for this research project will help to formulate the speed reduction factors for the New Zealand environment. This model will be referred to as the *modified Benekahal model*.

The operating speed at the approach can be estimated using the method explained in either chapter 3 or chapter 4. The model (ie equation 4.1) described above is used in section 6.6. The speed reduction due to surface condition (eg unswept new chipseal), can be used in equation 4.1 where the variable is defined as speed reduction due to all other factors (V_a). In section 6.6, this reduction (V_a) is assumed to be 10km/h for the open road (see section 3.3).

5 Data collection

The site data collected for the engineering analysis is shown in appendix A. In addition, the speed and headway data (see section 5.2) were used for both the engineering and psychology analyses. The data sheet is primarily dependent on variables which are related to the Benekohal et al (2004) speed estimation model discussed in chapter 4.

5.1 Road work site selection

Eight road work sites were selected for surveying within the Greater Wellington region, six on 100km/h and two on 50km/h stretches of road. There were two main criteria for selecting the work sites. The first was the TSL used on the site. There were three levels of this for the 100km/h roads: 70km/h, 50km/h and 30km/h. For the 50km/h roads there was only one level: 30km/h.

The second criterion was the level of visibility through the work site. For continuous visibility sites the entire work site was visible from the beginning of the taper. For non-continuous visibility sites some of the site was obscured by vertical or horizontal curves.

For the purposes of this paper the sites will be referred to primarily by their site number, as shown in table 5.1.

Table 5.1 Site numbers, conditions and test dates of the eight sites

Site number	Speed limit (km/h)	TSL (km/h)	Visibility	Date of testing	Site name
1	100	70	Continuous	14/02/2008	Western Hutt Road
2	100	70	Non-continuous	5/02/2008	River Road
3	100	50	Continuous	29/10/2007	Greytown
4	100	50	Non-continuous	10/03/2008	Kaitoke
5	100	30	Continuous	26/03/2008	Coast Road
6	100	30	Non-continuous	15/01/2008	Te Horo
7	50	30	Continuous	18/01/2008	Cambridge Terrace
8	50	30	Non-continuous	8/02/2008	Eastern Hutt Road

As well as the two main criteria, there were two other characteristics that influenced site selection. The first was that the site should not be under constant control by a manual traffic controller using stop/go paddles. Only site 8 had a manual traffic control in place but it was set at go in both directions for most of the time speed data was recorded, with no data being used for the times when traffic was stopped.

The second was that the site was far enough away from any intersections to ensure that the influence of turning traffic on vehicle speeds was minimised. For six of the sites the minimum distance an intersection was from the areas where speeds were measured (either approach or entry speeds: see section 5.2) was 100m. However, for two sites there was an intersection either between the approach and entry measurements (a landfill entry for site 5) or just after the position of the CEOS infrared traffic logger (TIRTL) (site 8). In the first instance vehicles using the landfill never had their approach speeds measured, as the approach speeds were measured at a point past the landfill entry. It was also easy to judge which vehicles had used the landfill, so they were noted in the data. Site 8 was in an industrial area, and the intersecting street was a short, dead-end street only leading to businesses. Very few vehicles either

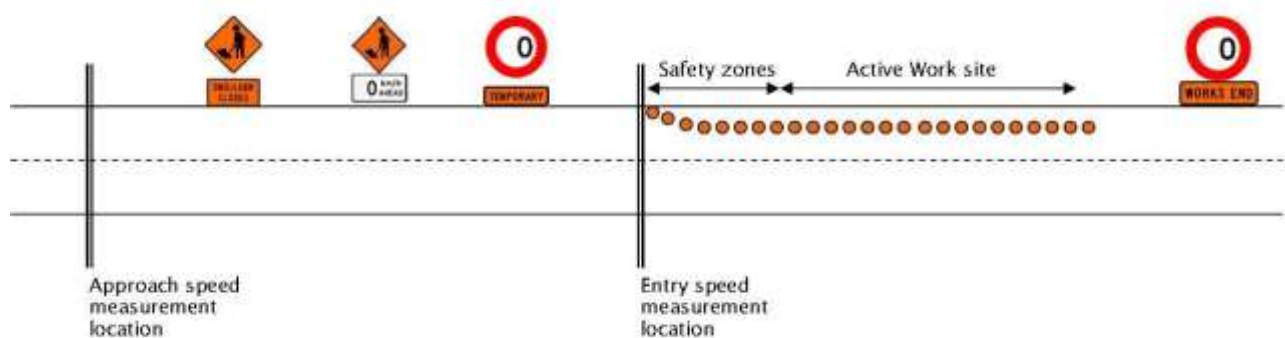
entered or exited this street, and no data from these vehicles was included in the analysis, so the effect of this intersection on speeds was not a concern.

It would have been useful to include the traffic management plans used by the contractors on each site, but these plans were not obtained at the time of testing and hence have not been included. Note however that whether the work site complied with the CoPTTM guidelines was recorded on the field data collection sheet (appendix A). All the sites were informally assessed on CoPTTM compliance, and all were found to be compliant for at least the direction we were monitoring. Any concerns regarding compliance were addressed by talking to the on-site team before measuring began.

5.2 Vehicle speed survey

Driver speeds were measured on approach to the work site, as well as from at least one location at the work site (see figure 5.1). Approach speeds were measured from a position at least 100m in advance of the first warning sign (TW-1). Measurements were taken with a Laser Technology Inc. 20-20 Marksman speed gun. Driver site entry speeds were measured at the start of the taper¹ using the TIRTL. A researcher was positioned adjacent to the TIRTL and recorded vehicle number plates. Where possible, vehicles were matched on site-approach and site-entry speeds.

Figure 5.1 Generic illustration of the speed measurement locations used for the project



Speed measurement at a site occurred until approximately 200 number plates had been recorded. This meant that more time was spent on site on lower-volume roads. For seven sites there was a control condition where none of the research team was on site, ranging from 20 to 35 minutes. This was to enable us to determine whether having an additional person on site affected work zone entry speeds and, if so, by how much. For site 5 the traffic flow was so low that a control condition was not feasible, as collecting the 200 number plates took almost six hours. Table 5.2 presents the overall time spent at each site, and in the control condition, for each site, as well as the number of free-travelling vehicles (see chapter 6) recorded for each site overall and in the control condition.

¹ The start of the taper was chosen as the position to measure site entry speeds through discussion with the project's steering group. The reasoning was that ideally drivers should be travelling at the TSL when entering the site.

Table 5.2 Time spent on site and vehicles measured, both overall and for the control condition alone

Site number	Time on site		Vehicles measured entering site ^a	
	Overall	Control condition	Overall	Control condition
1	1h 36m	30 m	565	383
2	1h 0m	20 m	292	192
3	3h 35m	35 m	308	102
4	2h 0m	20 m	275	57
5	5h 50m	NA	261	NA
6	1h 35m	30 m	406	287
7	2h 50m	30 m	357	122
8	1h 45m	20 m	309	98

^a These values only include free-travelling vehicles

5.3 Driver survey

5.3.1 Participants

For each site 100 drivers were selected to be surveyed. Drivers of commercial vehicles were excluded from being surveyed, as were motorcycle riders. Vehicle number plates were entered into the NZTA MotoChek system to obtain addresses. To ensure confidentiality the actual addresses were not viewed by any member of the research team. The letter sent to the drivers (see appendix B) asked that the person most likely to have been driving on the day in question fill in the survey. It is possible, however, that the person who filled in the survey was not the driver on the day.

In total 469 surveys were returned, resulting in a response rate of 58.6%. However, three surveys for site 6 could not be linked to a specific vehicle and were excluded from the analyses. As well, one respondent to the site 5 survey said they were not at that location when we were there, so they were also excluded from the analyses. Five additional surveys were returned after the analysis was completed. Table 5.3 presents the overall returns from each site.

Table 5.3 Survey returns by temporary speed limit and visibility condition. Numbers in brackets represent surveys that could not be linked to specific vehicles

Speed limit	Visibility condition	
	Continuous	Non-continuous
100-70	60	62
100-50	58	61
10-30	54 (1)	60 (3)
5-30	56	49
After analysis	5	
Total returns	469	

The survey consisted of 86 mixed-type items (see appendix C for a full copy of the survey). As well as the survey, two photographs of work sites were included for reference for some of the questions. The first photograph was of a site the respondent had not been observed at (the previous site where testing had occurred), while the second was of the site where the respondent was observed. As there was no site before site 1, a photograph was taken and data was collected at a road work site that was unsuitable for the study. Appendix D presents the photographs used for this part of the study.

Fifteen items asked the respondent to rate how much they thought various aspects of road works in general affected the risk of a crash occurring. There were 12 items relating to specific sites, and these questions asked the respondents to examine the photographs. These were presented twice, first for the site where the respondent was not observed driving and then for the site where they were observed. Seven of the items asked about the likelihood of certain events occurring at the site pictured (eg 'loose stones chip the windscreen' or 'two motorists collide'). Three items asked about the perceived speeds at which the respondent, an average driver and a good driver would travel through the road works, and two items measured whether the respondent thought the site appeared active and whether they thought the TSL was appropriate for the conditions of the road.

Seventeen items examined attitudes: nine to speeding and eight to road works. Fifteen items asked for the **respondent's judgements** regarding the driving behaviours of the following three drivers: the respondent, an average driver and a good driver. The five behaviours were the speed each driver would travel in a 100km/h zone; the speed the driver would travel in a 50km/h zone; how often each driver would obey general speed limits; how often each driver would obey TSL; and how considerate each driver would be to other drivers.

Three questions asked about the respondent's perceptions of the power of their car, how cautious a driver they were, and how safe a driver they were, in relation to an average driver. Three other questions asked about the respondent's driving habits in relation to open road driving, and driving through road works when work was or was not occurring.

There were five general demographic items covering age, gender, income, occupation and level of education. Years of driving experience and licence type were measured by two items. Finally, two items measured how long it took the respondent to fill in the survey, and how difficult they found it.

6 Analysis

Sections 6.1 to 6.6 contain the engineering analysis, while sections 6.7 and 6.8 contain the psychological analyses. Section 6.7 overlaps with the engineering analysis, but applies tests of statistical significance to the speed data. As this paper may be of interest to both engineers and psychologists it was deemed appropriate to use two different techniques to analyse the same data.

The main vehicles of interest for this part of the survey were those that were free-travelling, ie their speeds were not constrained by the preceding vehicle. Determining whether a vehicle is free-travelling requires knowing its time headway. Time headway usually refers to the time between the front of one vehicle passing a specific point and the front of the following vehicle passing the same point (Vogel 2002), but this could not be calculated from the vehicle data. The time headway used for this research was the time difference between the leading vehicle being recorded by the TIRTL and the following vehicle being recorded. Any vehicles not detected by the TIRTL had approximated recording times entered based on the video footage of the site.

For this study a vehicle was considered to be free travelling if its time headway was 6s or greater, as per Tate and Turner (2007) and Vogel (2002). Analyses using speed data primarily used the free-travelling speed. Instances where this was not the case have been specified in the text. In the analyses the following free-travelling speeds were considered: the 5th percentile, the mean, the 85th percentile, the variance of the approach speed distribution and the entry point speed distributions. See section 5.2 for more details on where speeds were measured.

6.1 Sample size for speed measurement

The required sample size for the engineering analysis was estimated using the formula given in traffic studies (Austroads 1992). The sample size for 95% desired confidence level and 85th percentile speed estimation with the permitted error of $\pm 5\text{km/h}$ was estimated to be 38. The error of $\pm 5\text{km/h}$ was determined from the necessary accuracy for model assessment, as well as from the tolerance for speed limit enforcement in New Zealand. (In general, drivers travelling within 10km/h of the posted speed limit are not ticketed.) The estimated speed variance ranged from 25 to 160km^2 but was assumed to be 160 for determining the maximum possible error. The actual number of free-travelling vehicles varied from 69 to 196 for each site at the approach and entry locations. If the sample size is 69 then the error in mean speed estimation is less than $\pm 2\text{km/h}$ for. If the sample size increases then the error will decrease. For the following analyses errors of no more than $\pm 4\text{km/h}$ in 85th percentile speed and no more than $\pm 2\text{km/h}$ in mean speeds were considered.

6.2 Speed data for engineering analysis

The speed survey examined whether drivers altered their speed due to perceived speed limit enforcement. Specifically, when drivers identify the possibility of a speed measuring system on or near the road, they consider slowing down and following the speed limit. A small number of vehicles with a radar detection system could detect our speed gun and reduce their speed, but this effect was assumed to be negligible in our measurement. We expected the TIRTL to have less of an effect on speed reduction by drivers because of the lessened likelihood of recognition, and therefore detection, than standard speed measuring devices (eg cables across the road). To minimise driver speed reductions related to a car parked on the side of the road we initially planned to use the speed gun from either a hidden location or from an OPUS van (with company brand icon). However, it was finally decided to use the speed gun from an unobtrusively parked

white station wagon. The effect of the presence of the car was expected to be minimal but it was actually considerable and therefore cannot be neglected. Figure 6.1 shows the 85th percentile speed at each approach and the respective permanent speed limit.

Figure 6.1 Operating (85th percentile) and mean approach speed for each site

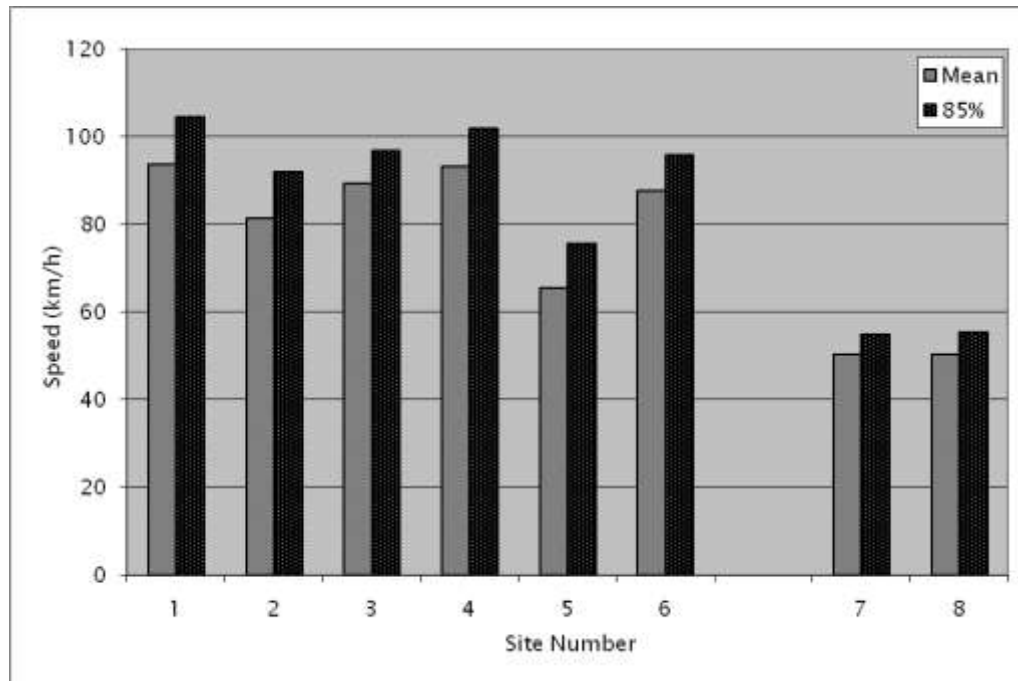


Figure 6.1 shows the approach speeds were lower at sites 2, 3, 5 and 6 than at sites 1 and 4. The measured 85th percentile approach speed was greater than the speed limit at sites 1 and 4, where differences, including geometry effects, were very small compared with the other open road sites.

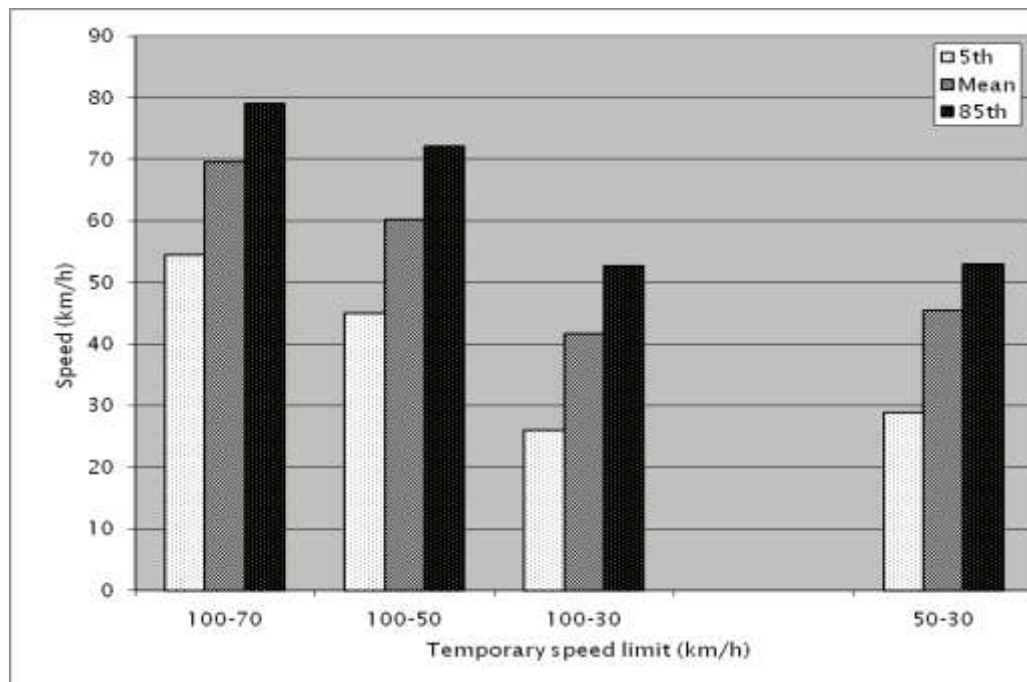
The reason why some vehicles were recorded travelling over the speed limit of 100km/h at the approach to sites 1 and 4 could be explained by the location of the speed guns. No car was used for site 1 where approach speed measurements were taken from a highway overbridge. The car parked for approach speed measurement at site 4 was some distance from the location where the entry speed was measured.

For section 6.6, the approach speed to the work zone was used directly for input into the model rather than being estimated using the method outlined in chapter 3. The measured work zone speeds were possibly influenced by the car effect. This car effect was included in the predicted work zone speed by using the approach speed as the measured entry speed for the model. This helped to make a correct comparison of the predicted and measured work zone speeds.

6.3 Speed at entry

Figure 6.2 shows the speed statistics at the entry of the work zones from the continuous sites. Crashes were rare events. A small proportion of people should not be neglected such as the drivers who drove below 5th percentile or above 85th percentile speed. Figure 6.2 shows that 5th percentile speeds were less than the TSL.

Figure 6.2 5th percentile, mean, and 85th percentile speeds at the entry of the continuous work zone in sites across speed limit change conditions



In figure 6.2 the site with a 70km/h temporary speed limit showed a mean speed of approximately the TSL and a 5th percentile of around 55km/h, indicating that a number of drivers were willing to travel at less than the TSL. A point that should be **noted is that it's undesirable** to force these drivers to speed up and the reason for this has been discussed in the literature review. This trend occurred at one of the heavy construction sites at SH2 and Dowse Drive at the Petone interchange. The mean and the 85th percentile speeds measured at the other three sites were around 10km/h above the TSL. The two 30km/h TSL sites were re-surfacing with chipseal. At these two sites, there were risks of the chips causing damage and this may have been the reason why speed was reduced. The more likely reason was the lower number or lack of vehicles in the opposite site or the near the front, minimising the chance of chips being thrown up and damaging windscreens. Furthermore, the 5th percentile speeds were below the TSL.

The 5th percentile free vehicle speeds in figure 6.2 show there were a number of people driving below the TSL. Research by Solomon (1964), Cirillo (1968), Tignor and Warren (1989) and Harkey et al (1990) has shown that crash rates increase when mean speed of traffic increases. Overall, while drivers in the 5th percentile speed bracket appeared to be closer to the TSL, those in the 85th percentile and the mean were faster than the TSL at three sites (ie sites with 50 and 30km/h limits). The 85th percentile speeds were approximately 20km/h greater than the TSL for three sites, with TSL of two 30km/h sites and the 50km/h site. Drivers with 5th percentile speed have a greater chance of nose to tail accidents if the following vehicle approaches with a shorter headway distance and drivers are distracted by other activities (eg construction work). Frith and Patterson (2001) noted, 'Encouraging or forcing slow drivers to speed up beyond their comfort levels is contrary to accepted road safety wisdom. If these drivers subsequently became involved in a crash, any injuries would be much more severe than if they had travelled at slower speed'.

Figure 6.3 5th percentile, mean and 85th percentile speeds at entry of the work zone in non-continuous sites

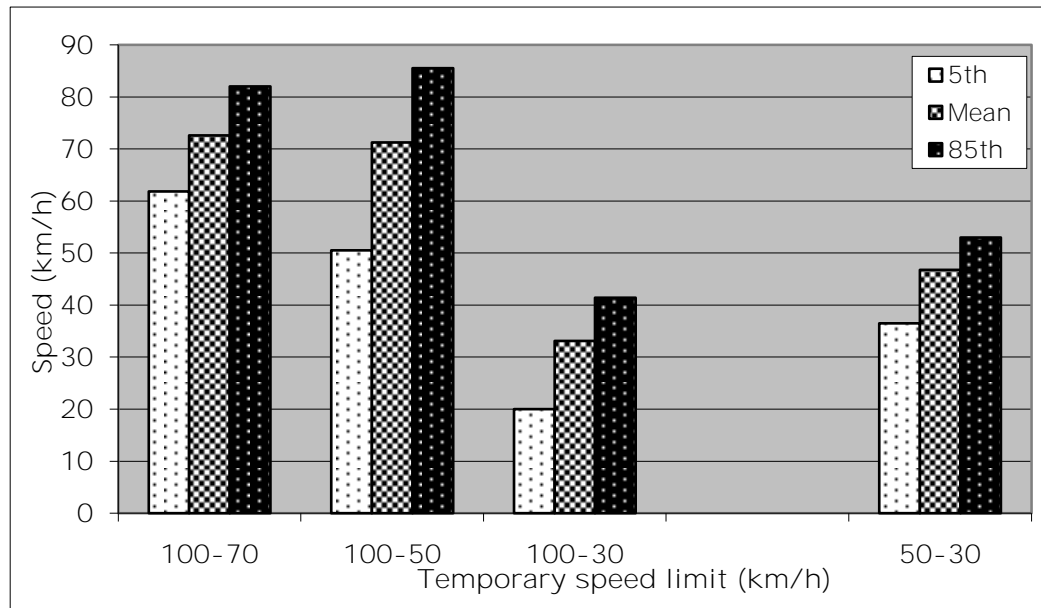


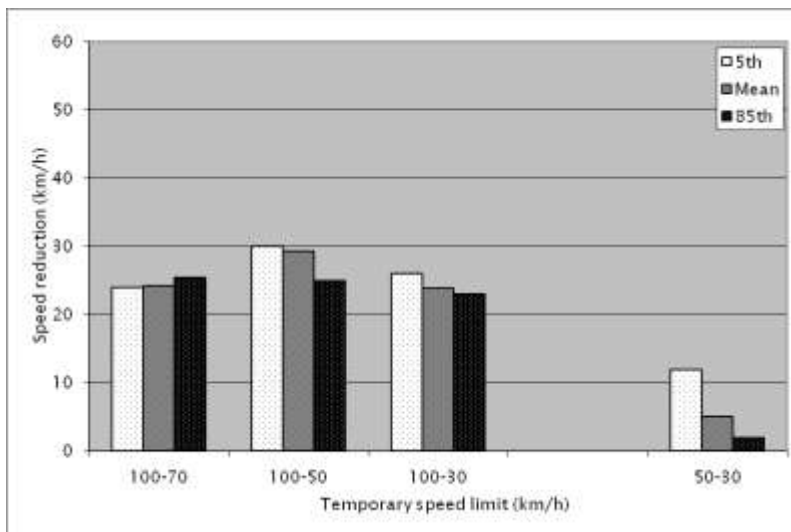
Figure 6.3 shows speed statistics calculated from speed measurement data at the entry of the work zone site in the non-continuous sites. Figure 6.3 confirms the earlier data, with results showing the 5th percentile speed was closer to the TSL than the mean and 85th percentile speeds. The point to be noted is that for half of the non-continuous sites the 5th percentile speed was equal to or higher than the TSL. On the other hand, at all of the continuous sites the 5th percentile speeds were below the TSL. The mean and 85th percentile speeds were not considerably different between the continuous and non-continuous sites. Overall, consideration of results and the possible variation caused by the sample size for speed measurement discussed previously, indicate that more in-depth research is necessary to confirm the geometry or site visibility effect on the three levels of speed limits. However, this was not the main focus of this research.

This analysis shows that for both continuous and non-continuous sites there is a need for further improvement in work zone design to bring the mean and 85th percentile speeds down.

6.4 Speed reduction performance

Speed reductions were calculated by subtracting the entry speed from the approach speed. Speed reductions were calculated for the 5th percentile, mean and 85th percentile speeds. Speed reduction performances were plotted separately for each visibility condition. The graph shown in figure 6.4 has been plotted for the continuous visibility work zones.

Figure 6.4 Differences between the site approach and entry 5th percentiles, between the site approach and entry means, and between the site approach and entry 85th percentiles, for the continuous sites



The reduction in the 5th percentile, the mean and the 85th percentile speed for each of the different sites did not vary much except where there was a 50 to 30km/h speed limit drop. The 5th percentile speeds were around the speed limit but not the mean or 85th percentile for all the sites shown in figure 6.2. In figure 6.4, even the mean and 85th percentile speed reduction at the sites which had a 100 to 70 or 100 to 30km/h speed limit drop had almost the same speed reduction. This indicates drivers were not following the TSL signs and the temporary traffic management plan was not effective in terms of drivers' speed reduction for those sites. This indicates an improvement is necessary in temporary traffic management plans or TSL estimations.

The graph shown in figure 6.5 is plotted for the non-continuous work zones. The figure demonstrates that speed reductions increase as the speed limit reduction increases, but that further speed reductions are necessary to ensure driver speeds match the TSL.

Figure 6.5 Differences between the site approach and entry 5th percentiles, between the site approach and entry means, and between the site approach and entry 85th percentiles, for the non-continuous sites

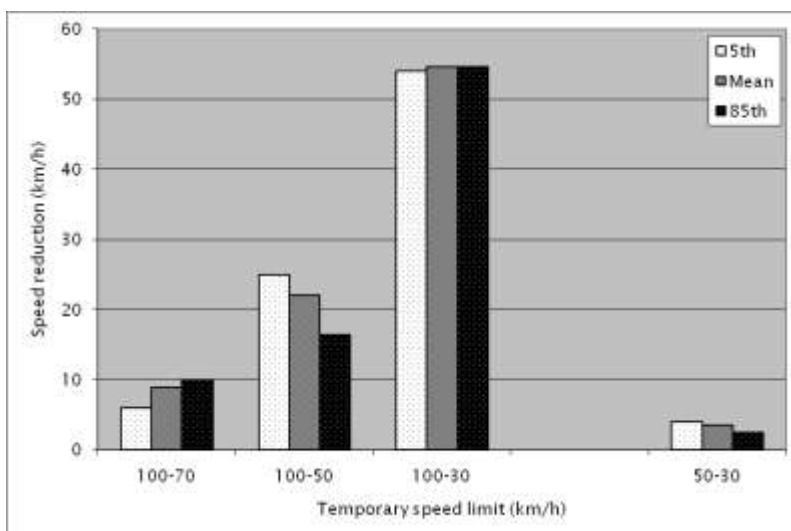


Figure 6.5 shows that speed reductions more closely follow the speed limit reduction at the non-continuous sites compared with the continuous sites. This is because the site with the 100 to 30km/h speed limit reduction had a lower speed reduction at a continuous site (see figure 6.4) than at a non-continuous site (see figure 6.5). These two site conditions are quite different. In reality the entry speeds at the non-continuous site were influenced by additional factors, including:

- There were more than 10 workers and heavy trucks at the non-continuous site but no workers or trucks at the continuous site.
- The speed measurements for the non-continuous site only included vehicles when there was no congestion at the approach or entry and the go signal was in place. The continuous site speed measurements were taken with no people or a manual traffic controller on site.
- When considering the road geometry, the continuous site had a low traffic flow with sharp curves before and after the site.
- There was more dust due to construction work at the non-continuous site than at the continuous site.
- Contraflow was used at the non-continuous site, whereas there were no changes to the lanes for the continuous site.

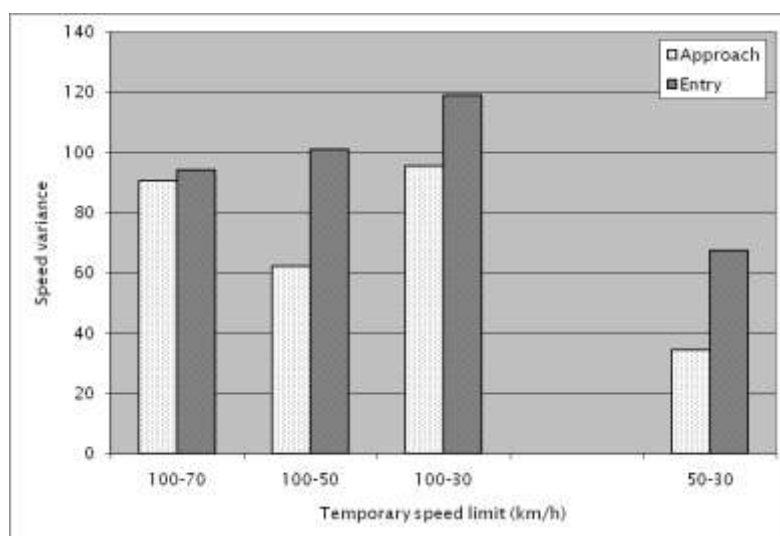
Considering these findings from the continuous and non-continuous sites, it is necessary to improve site design and/or the TSL estimation procedure.

6.5 Speed variance performance

Speed variance was calculated from the free-travelling speed distribution obtained from the approach and entry speed measurements individually. At least 68 free-travelling speed measurements were obtained at each location.

The speed variance plotted for the continuous visibility sites is shown in figure 6.6 and for the non-continuous visibility sites in figure 6.7.

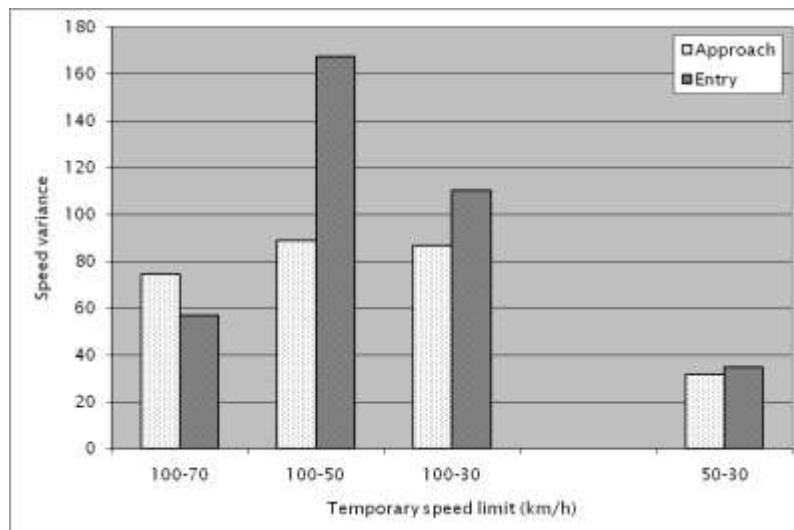
Figure 6.6 Site approach and site entry speed variances for the continuous sites



By considering figures 6.6 and 6.7 the increase in the speed variance between approach and entry was high for the sites where the speed limit was reduced from 100 to 50km/h. Changes in speed variance

were small at the site with a speed limit reduction of 100 to 70km/h compared with the sites with the speed limit reduction 100 to 50km/h or 100 to 30km/h. However, these small changes may have been affected by other factors at the sites. In this study we can make overall comments by examining all four sites but we will not be able to comment about the speed reduction performance at individual sites because there were other variables present such as the number of people working, heavy equipment or lateral clearance.

Figure 6.7 Site approach and site entry speed variances for the non-continuous sites



Speed distribution data at the approach and the entry shows that:

- the 85th percentile speed was considerably higher than the TSL for most sites
- the speed variance increased at the entry point of most work zones.

Migletz et al (1999) demonstrated that the crash rate was lower when the percentage increase in speed variance was low (see figure 2.1). The above two bullets points indicate that the crash risk was high at sites in our study. It is important to consider these two points in the future and develop a guide for TSL estimation procedure at work zones in New Zealand if we want to reduce crashes in the future.

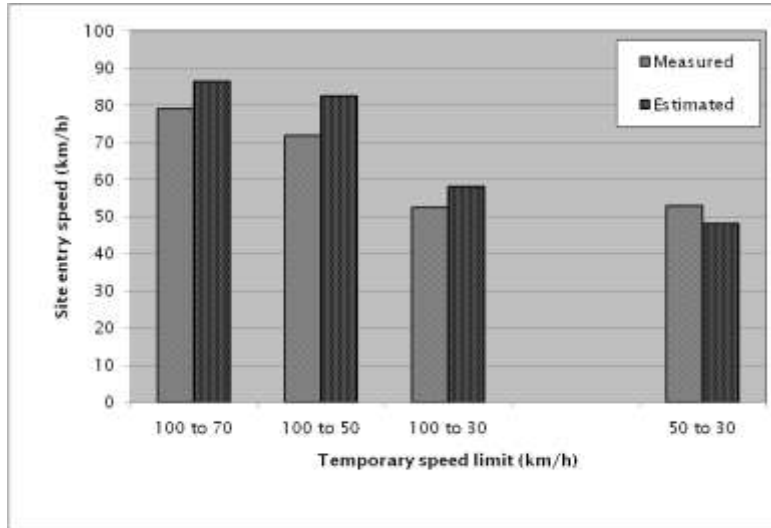
6.6 Assessing the speed prediction model

Data regarding specific site conditions is shown in the sample data sheet in appendix A. These field variables were collected for assessment purposes for the modified Benekohal model (see chapter 4).

The measured and estimated entry speeds for the continuous work zone sites are shown in figure 6.8. The measured speed from the second and third sites, where the speed limits changed from 100 to 50km/h and 100 to 30km/h, deviated considerably from the estimated speed. The second site featured a centreline lane crossover which had an effect on speed reduction and was not considered in the model assessment. The model allowed for other reduction factors but at that stage the amount of reduction was unknown and therefore these factors were not considered in the model assessment. This was mentioned earlier in the literature review. Speed reduction by lane crossovers should be researched in the future. The third site was operated with a stop/go sign but the measurements were taken only when the go signal was in place and there were no queued vehicles at the entry. It appears that the sign had some effect. If these

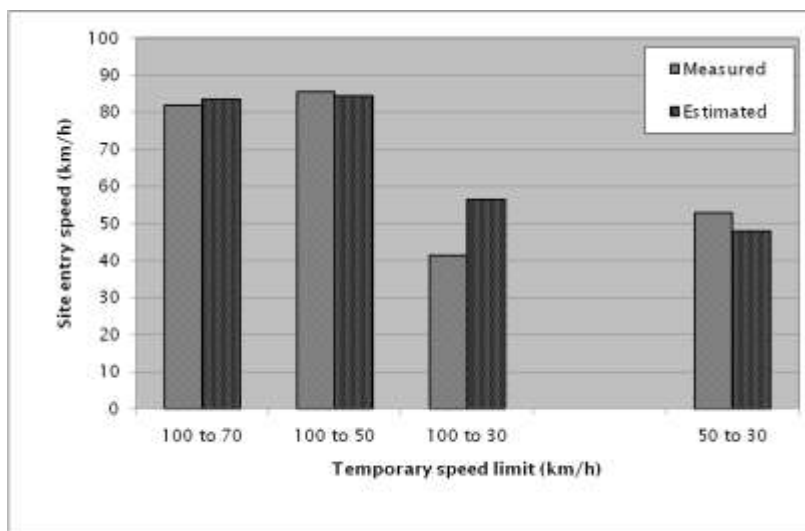
two reductions were considered then the differences in the estimated and observed speeds would be less than 10km/h.

Figure 6.8 The measured and estimated entry operating-speeds for the continuous sites



The difference between measured and estimated speeds at the non-continuous site where the speed limit reduction was 100 to 30km/h was higher than at other sites and this is shown in figure 6.9. This site had a special feature which is discussed in section 6.4. Speed reductions due to lane closure, stop/go control and construction dust are not considered in the modified Benekohal speed estimation model. This is the most obvious reason why the speed difference between estimated and observed operating speeds is higher than 10km/h.

Figure 6.9 The measured and estimated entry operating-speeds for non-continuous sites



The measured, rather than estimated, approach speed was used to minimise the effect of estimation on the model assessment. A thorough statistical analysis with confidence levels could not be provided for the model assessment due to the above-mentioned approximation.

In this assessment the model worked effectively but accuracy could be improved with further research. The following conclusions can be drawn from the model assessment.

- The estimated speed from the model was approximately equal to the measured operating speed at most of the sites except one where there were special circumstances.
- In three out of eight sites the estimated speed was greater than measured speed. However, at these particular three sites there were other factors influencing drivers.
- There were no sites in which the estimated speed was substantially less than the measured speed.

By considering all three points, the model can be used to estimate the operating speed for the work zone site-specific plan assessment. This will help to identify any needs for site safety improvement or traffic management plan improvements for determining the TSL. This is discussed in detail in chapter 7. At this stage the accuracy of predicting the operating speed is good enough to improve the TSL estimation when considering the difference between operating speeds and existing TSL for all eight sites. The model will certainly help to identify the deficiencies in temporary traffic management plans or site design regarding the correct TSL.

6.7 Vehicle speed survey

6.7.1 Relationships between vehicle approach speeds and entry speeds

Correlations were calculated between vehicle approach speeds and entry speeds for each site. Correlations with approach speeds were based on the on-site condition, as approach speeds were not recorded in the off-site condition. The correlations are presented in table 6.1.

Table 6.1 Correlations between approach and entry speeds across temporary speed limit and site visibility conditions, for all vehicles and free-travelling vehicles. Sample sizes are provided in brackets

Temporary speed limit condition (km/h)	Site visibility condition			
	Continuous		Non-continuous	
	All vehicles	Free-travelling vehicles	All vehicles	Free-travelling vehicles
100 to 70	0.26*** (266)	0.39*** (86)	0.34*** (225)	0.43*** (96)
100 to 50	0.15** (273)	0.18** (179)	0.45*** (252)	0.48*** (169)
100 to 30	0.34*** (172)	0.41*** (148)	0.21** (214)	0.48*** (83)
50 to 30	0.17** (294)	0.2** (196)	0.36*** (244)	0.36*** (149)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Approach speeds and entry speeds were consistently and positively correlated. This is an intuitive finding, and simply indicates that people who tend to travel faster in general also travel faster in work zones. As well, the correlations were stronger when only free-travelling vehicles were considered for seven of the eight sites, with the correlations being the same for site 8. The stronger relationship between approach and entry speeds when the vehicles are free travelling supports the use of only these vehicles in the following analyses.

6.7.2 Differences between approach and entry speeds, and temporary speed limit and entry speeds.

Paired sample t-tests were conducted on the approach and entry speeds for each site to test whether speeds decreased at the site. As well, single sample t-tests were conducted for each site to assess the difference between the observed mean speed and the TSL. The results of these analyses are presented in table 6.2. There were statistically significant speed decreases between the approach and site entry speeds for all sites. However, for all sites except site 6 (the continuous 100–70 km/h site) the mean site entry speeds were significantly higher than the posted TSL, although in some cases only moderately so (approximately 3km/h higher for sites 2 and 4).

Table 6.2 T- tests and descriptive statistics for comparisons between approach and site entry speeds and TSL and site entry speeds

Site	Mean speed (km/h)		TSL (km/h)	SD			Entry speed t- tests		
	Approach	Entry		Approach	Entry		df	Vs. approach ^a	Vs. TSL ^b
1	93.7	69.5	70	9.5	9.7		68	18.99***	-0.46
2	81.6	72.6	70	8.6	7.6		95	10.08***	3.41***
3	89.4	60.9	50	7.9	10.1		178	33.79***	13.55***
4	93.3	71.2	50	9.4	12.9		168	24.31***	21.33***
5	65.5	41.6	30	9.8	10.9		147	25.75***	12.97***
6	87.7	33.1	30	9.3	10.5		82	49.09***	2.66**
7	50.5	45.4	30	5.9	8.2		195	7.88***	26.16***
8	50.3	46.8	30	5.6	5.9		148	6.65***	34.63***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6.7.3 Speed comparisons between visibility conditions

Independent and single sample t-tests were conducted to test whether driver approach and entry speeds for each level of the TSL differed depending on the site visibility condition: continuous or non-continuous:

Table 6.3 presents the results from these analyses. The approach and entry speeds differed significantly for three of the four TSL conditions, the exception being where the speed limit was reduced from 50 to 30km/h. There was, however, no consistent trend regarding which visibility condition produced the higher speeds. For instance, entry speeds were higher at the non-continuous visibility sites where speed limits were reduced from 100 to 70km/h and 100 to 50km/h, but not for the other two TSL conditions. As well, there was only one TSL condition (100 to 50km/h) where the higher approach speed was also matched by a higher entry speed. This indicated that factors other than site visibility affected driver speed choices.

Table 6.3 Comparison of approach and entry speeds across visibility conditions for each level of temporary speed limit. The higher mean for each comparison is in bold text

Temporary speed limit condition (km/h)	Mean (km/h)		SD		N		t	df
	C	NCV	C	NCV	C	NCV		
100-70								
Approach	93.9	81.6	9.1	8.6	86	96	9.37***	180
Entry	69.2	72.9	10.3	7.5	75	105	-2.8***	178
100-50								
Approach	89.4	93.3	7.9	9.4	179	170	-4.16***	347
Entry	60.5	70.7	10.3	13.2	196	177	-8.45***	371
100-30								
Approach	65.5	86.8	9.7	10.1	152	108	-17.12***	258
Entry	39.9	32.6	10.9	10.2	226	99	5.64***	323
50-30								
Approach	50.5	50.4	5.8	5.7	198	154	0.18	350
Entry	45.5	46.3	8.3	6.5	226	170	-1.05	394

* p < 0.05, ** p < 0.01, *** p < 0.001

Note: C = continuous visibility, NCV = non-continuous visibility

6.7.4 Comparison of on-site and off-site speeds

To examine the effect of having an additional person in a high-visibility jacket on site, t-tests were conducted to compare the on-site and off-site free-travelling site entry speeds for the seven sites where this was possible. Note that the only difference between the on-site and off-site conditions was that project members involved in the data collection were not visible on site; any workers at the site were still visible. The results are presented in table 6.4. The 85th percentile speeds for the on-site and off-site conditions have been included for comparison.

Table 6.4 Comparison of work site entry speeds for the people on-site and people off-site conditions. The higher mean or 85th percentile for each comparison is in bold text

Site	Mean (km/h)		85 percentile (km/h)		SD		N		T	Df
	On site	Off site	On site	Off site	On site	Off site	On site	Off site		
1	69.2	70.4	79.2	80.0	10.3	8.9	75	78	-0.79	151
2	72.9	78.9	82.0	91.5	7.5	9.8	105	69	4.6***	172
3	60.5	63.4	72.0	74.4	10.3	10.8	196	70	-2.00*	264
4	70.7	67.1	85.3	81.0	13.2	15.7	177	40	1.51	215
6	32.6	33.8	41.0	42.7	10.2	8.1	99	81	-0.87	178
7	45.5	48.2	53.0	55.0	8.25	7.3	226	79	2.6***	303
8	46.3	46.4	53.0	53.0	6.45	6.0	170	60	-0.06	228

* p < 0.05, ** p < 0.01, *** p < 0.001

Overall mean entry speeds were higher when research staff members were not visible on site. The increases ranged from around 1.2km/h to just over 6km/h. At site 5 there was effectively no increase, and the speeds were about 3.5km/h higher in the on-site condition for site 7. The 85th percentile speeds followed the same trend as the mean speeds, and the magnitudes of the differences were similar.

6.7.5 Approach speeds and changes in speed variance

To examine whether the increase in speed variances from the approach to the site entry was associated with approach speeds, vehicles were divided into two groups: those with approach speeds below the mean and those with approach speeds above the mean (*slower* and *faster* vehicles). Table 6.5 presents the mean speeds for slower and faster groups at the site approach and site entry, and the change in speed. Given the way the two groups were created the difference in mean approach speeds across the sites is trivial. The speeds of the two groups are closer for the entry speeds, which is due to the faster vehicles reducing speed to greater extent than the slower vehicles. This is also a fairly trivial finding, as the faster vehicles had more speed to lose. However, these findings do not indicate whether the increased speed variance at the site compared with the approach can be completely attributed to the faster vehicles.

Table 6.5 Mean site approach and entry speeds for vehicles above and below the mean approach speed, grouped by site

Site	Approach (km/h)		Entry (km/h)		Difference (km/h)	
	Slower	Faster	Slower	Faster	Slower	Faster
1	87.2	101.0	62.3	66.3	24.9	34.7
2	75.5	89.5	70.1	73.2	5.4	16.3
3	82.8	95.4	57.1	59.8	25.7	35.6
4	85.2	99.7	64.1	74.0	21.1	25.7
5	57.6	73.8	42.0	45.7	15.6	28.1
6	81.8	96.6	24.2	28.1	57.7	68.4
7	47.3	54.9	44.7	45.8	2.6	9.1
8	46.5	54.2	44.2	46.7	2.3	7.5

Table 6.6 shows the speed variances for the slower and faster groups at site approach and site entry, as well as the change in variance for each group. The speed variance at the entry of each site was higher than on the approach. However, while neither group had consistently higher speed variances at the site approach, the faster group had higher variances at site entry compared with the slower group. Combined, these findings indicate that while both slower and faster vehicles contributed to the increase in speed variance at site entry compared with site approach, the faster vehicles contributed to the increase to a greater extent.

Table 6.6 Speed variances at the site approach and site entry for vehicles above and below the mean approach speed, grouped by site

Site	Approach		Entry		Difference	
	Slower	Faster	Slower	Faster	Slower	Faster
1	34.7	23.1	73.0	88.4	38.3	65.4
2	23.1	28.8	40.0	77.7	17.0	48.8
3	26.6	18.9	89.1	105.7	62.5	86.8
4	49.0	26.8	128.3	191.7	79.3	165.0
5	30.8	42.5	96.4	120.4	65.6	78.0
6	39.9	31.9	80.4	134.1	40.4	102.2
7	18.3	9.1	52.7	75.9	34.4	66.8
8	15.8	9.2	30.2	55.1	14.4	45.9

6.7.6 Comparison of speeds at the two recording locations for site 3

At site 3, work site entry speeds were measured at two locations due to the actual work area being more than 600m from the start of the taper. The first location was at the start of the taper, the same location as used at the other seven sites. The second location was approximately 500m further in, closer to where the actual work was occurring (see figure 6.10). To examine whether vehicle speeds differed at these two locations, a t-test was conducted. As well, a t-test was used to test the difference in approach speeds for each site measurement location, as a difference in speeds within the site may have been due to speed differences approaching the site. The results from these t-tests are presented in table 6.7. Although the entry speeds were lower at the 500m measurement location, this difference was not statistically significant. The difference in approach speeds was significant, with speeds being lower when site entry speeds were measured at the second location.

Figure 6.10 Vehicle speed measurement locations for site 3

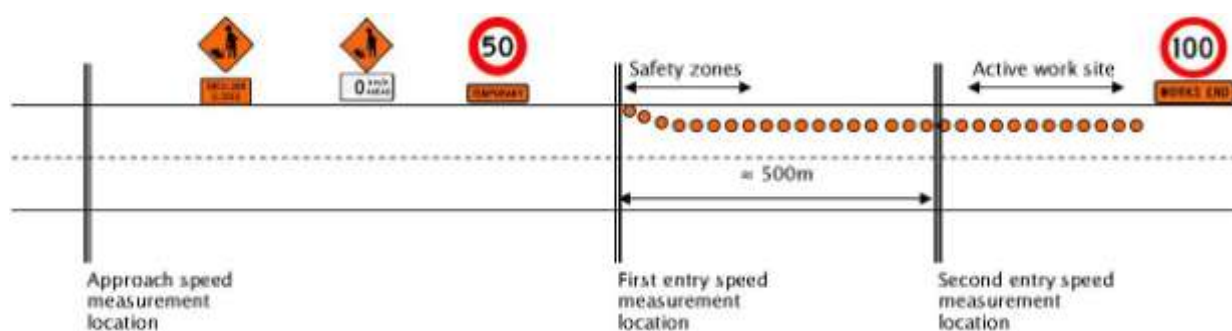


Table 6.7 Comparison of driver speeds at the start of the work site and 500m past the start for site 3

Speed measurement	Mean (km/h)		SD		N		t	df
	Taper	500m	Taper	500m	Taper	500m		
Site approach	91.5	87.7	7.0	8.2	81	98	3.34**	177
Site entry	61.4	59.2	10.4	9.7	81	98	1.5	177

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6.7.7 Comparison of approach speeds with post-work speeds for three sites

Speeds were measured at three of the sites following the completion of the works. These were sites 4, 7 and 8. The other sites were deemed unsuitable for post-work testing due to the works not being completed (sites 1 and 2), distance (sites 3 and 6), or limited traffic flow (site 5). Speeds of free-travelling vehicles only were measured using the speed gun at the location where the TIRTL was positioned.

Table 6.8 presents the descriptive statistics for each site and condition and the results of the t-tests comparing the means. Speeds recorded after the works were finished were consistently higher than speeds during the works.

Table 6.8 Comparison of site speeds during works and after works were completed

Site	N		Mean (km/h)		SD		t	df
	During	After	During	After	During	After		
4	143	52	71.7	97.5	13.3	7.6	-13.25***	193
7	195	57	45.9	53.3	8.06	4.9	-6.53***	250
8	147	55	46.7	54.9	6.62	4.4	-7.80***	200

p < 0.05, ** p < 0.01, *** p < 0.001

6.7.8 Repeated driver measurements

Site 5 was a dead-end road. This meant that vehicles which passed the TIRTL when leaving the site had to pass it on the way back. This provided the opportunity to take repeated measure of specific driver speeds, whereas repeated measurements of the same driver were rare at the other sites. This enabled us to **examine how consistent drivers' speed behaviours were, as a single measurement may not be fully representative of an individual's usual behaviour (eg Haglund and Åberg 2002; Wasielewski 1984).** In total 106 drivers were confirmed to have been observed at least twice, with 11 of these observed three times and two observed four times. Due to the limited number of drivers who were observed more than twice the following analyses have been limited to two observations.

Correlations were calculated between driver speeds at and away from the work site, for both the first and second observations. As well, the correlations were calculated using only free-travelling vehicles. Twenty of the vehicles were observed entering or leaving the landfill, so the correlation between the work site speeds for the first and second observations was also calculated excluding these vehicles. Table 6.9 presents the correlations. All of the correlations were positive, although they were generally quite small. This finding highlights the increase in error of using only one observation of driver speed.

Table 6.9 Correlations between speeds for all vehicles observed twice at site 5. Sample sizes are in brackets

	Speed measurement location	1	2	3	4
1	First at work site		0.22* (105) <i>0.19 (85)</i>	0.13 (74)	0.28* (80)
2	Second at work site	0.26* (74) <i>0.23 (58)</i>		0.03 (75)	0.18 (81)
3	First off work site	-0.12 (50)	0.27 (51)		0.37** (70)
4	Second off work site	0.19 (56)	0.26 (57)	0.44** (50)	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note. Correlations for all vehicles are above the diagonal, those for vehicles with headways greater than 6s are below the diagonal. Correlations in italics exclude vehicles that entered the landfill.

6.8 Driver survey

6.8.1 Site specific items

Analyses were conducted on the 12 items relating to the photograph for the site the respondents were **observed driving through**. Correlations were calculated between the respondents' seven risk estimate items and the site activity and **appropriateness of the TSL items, and the respondents' site entry speeds** (see table 6.10). Of the 72 correlations calculated only one was significant: the item 'A motorist collides with work zone machinery' correlated significantly with entry speeds for site 8. For site 8 there was no heavy machinery on site or visible in the photo. The correlation was also positive, indicating that an increased perception that this would happen was related to a higher entry speed, so it is probably a meaningless correlation.

Table 6.10 Correlations between site-specific items and actual site entry speed

Item	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Loose stones chip windscreen	- 0.15	- 0.13	- 0.01	- 0.18	0.13	- 0.04	0.14	0.05
Dust impairs vision	- 0.05	- 0.13	- 0.04	- 0.02	0.14	0.00	0.19	0.14
A motorist collides with road working machinery	- 0.19	- 0.01	- 0.10	- 0.07	0.10	- 0.01	- 0.02	0.30*
Vehicles will take longer to stop	0.00	- 0.03	- 0.07	- 0.08	0.18	0.15	- 0.09	0.21
A road worker is injured by a passing motorist	- 0.16	- 0.04	- 0.07	- 0.22	0.08	0.09	0.01	0.05
Two motorists collide	- 0.09	- 0.01	- 0.09	- 0.07	0.18	0.09	0.10	0.07
A motorist is injured	- 0.16	- 0.05	- 0.02	- 0.09	0.16	- 0.03	0.17	0.07
The road works appear to be active	0.10	- 0.06	- 0.08	- 0.13	- 0.17	0.00	0.06	- 0.04
The temporary speed limit is not appropriate for the conditions of the road	0.10	0.16	0.06	0.24	- 0.03	0.02	0.01	0.01

Estimated entry speed								
Yourself	0.10	-	-	0.20	0.31*	0.07	-	-
An average driver	0.12	-	-	0.15	0.30*	0.09	-	-
A good driver	0.08	-	-	0.30*	0.25	0.12	0.02	-
Min N	58	60	52	60	53	55	54	45

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

An examination of whether the speed estimates (self, an average driver and a good driver) related to entry speeds was also conducted (see table 6.10). Only three of the possible 24 correlations were significant, **and only one of these was for the respondents' estimates of their own speed through the site.**

Correlations were also calculated between the site-specific items and the respondents' estimated speeds for themselves at the site (see table 6.11). While a higher percentage of the correlations were significant, most of them were not (60 out of 72 correlations in total).

Table 6.11 Correlations between site-specific items and estimated site entry speeds

Item	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Loose stones chip windscreen	-0.06	-	-0.04	-0.18	0.09	0.03	-0.09	-0.23
Dust impairs vision	-0.11	-0.19	-0.07	-0.10	0.06	0.08	0.19	-
A motorist collides with road working machinery	0.01	-0.3*	-0.06	-0.09	0.47***	-0.14	-0.23	-0.05
Vehicles will take longer to stop	0.13	-	0.01	-0.09	0.13	0.14	0.04	0.09
A road worker is injured by a passing motorist	-0.13	-	-0.01	-0.15	0.38**	-0.10	-0.19	0.00
Two motorists collide	-0.08	-	0.03	0.01	0.30*	0.09	0.23	-0.02
A motorist is injured	-0.20	-	0.01	-0.12	0.13	0.05	0.06	-0.11
The road works appear to be active	-0.09	-0.14	-0.14	-0.33*	-0.24	-0.19	-0.13	-0.27
The temporary speed limit is not appropriate for the conditions of the road	-0.01	0.12	0.07	0.38**	0.06	0.15	0.26	0.19
Min N	60	59	51	60	53	55	55	44

$p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Finally, two sets of **t-tests per site were conducted to examine how accurate the respondents' judgements** were for their own site entry speeds and the entry speeds of the average driver (taken here as the mean score for free-travelling vehicles). The results of these tests are presented in table 6.12

For the four sites with the 100 to 50km/h and 50 to 30km/h temporary speed reductions, respondents significantly underestimated their speed and that of the average driver. For the remaining four sites estimates were generally more accurate, with only two of the eight differences reaching statistical

significance, both regarding the average driver at the two 100 to 30km/h sites. There were no significant differences for the two 100 to 70km/h sites.

Across all but **two of the sites the respondents' estimates of their own speed were fairly close to the** posted TSL, no more than 4.5km/h above the limit and, for site 6, about 2.5km/h under the limit. Only at site 8 did the mean estimate appear to differ to a large extent from the TSL (approximately 10.5km/h over the TSL). This may indicate that the respondents were estimating their speeds from the posted TSL rather than from their perceptions of the work site presented in the photograph.

6.8.2 General risk items and site characteristics

The 15 general risk items describe certain characteristics that may or may not be present within a work site, such as workers on the side of the road or traffic delays. Each site characteristic was coded as present or absent for each of the **eight sites. If the drivers' risk perceptions affected their behaviours it was** expected that increased risk perceptions for present characteristics would be associated with lower site entry speeds. For instance, if a site had been recently chipsealed, higher scores on the item 'An unstable road surface such as gravel' should be associated with lower site entry speeds. Conversely, there should be no consistent relationships between the absent characteristics and entry speeds. This does not mean there should be no relationships, as higher risk perceptions may be related to lower speeds in general, but the relationships between driver speeds and the site characteristics should be stronger when the characteristic is present than when it is absent.

Table 6.12 Site by site comparison of estimates of own speed, and the speed of the average driver, with the actual speeds recorded

Site	TSL	Mean speed (km/h)		SD		df	Test
		Estimate	Actual	Estimate	Actual		
1							
Self	70	67.4	65.0	9.7	8.4	58	1.51
Average		71.3	69.5	13.6	NA	59	0.31
2							
Self	70	71.0	70.5	12.5	7.3	59	0.28
Average		75.5	72.6	12.5	NA	59	0.08
3							
Self	50	52.5	59.8	8.5	10.3	56	-3.95***
Average		57.0	60.2	10.9	NA	55	-2.23*
4							
Self	50	54.0	68.4	10.7	13.3	60	-7.33***
Average		59.8	71.2	12.0	NA	60	-7.47***
5							
Self	30	40.7	37.6	16.6	10.3	53	1.41
Average		47.5	41.6	17.5	NA	52	2.43*
6							
Self	30	33.9	31.9	8.8	10.9	56	1.15
Average		38.5	33.1	10.6	NA	55	3.82***

Site	TSL	Mean speed (km/h)		SD		df	Test
		Estimate	Actual	Estimate	Actual		
7							
Self	30	33.3	45.4	7.0	8.0	55	-7.88***
Average		38.9	45.4	7.6	NA	53	-6.34***
8							
Self	30	34.2	46.5	8.6	4.9	45	-7.81***
Average		38.2	46.8	8.9	NA	45	-6.53***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Self tests were conducted using dependent means t-tests and the average tests were conducted using single-sample t-tests.

The results of these analyses are presented in table 6.13 with the correlations for the present characteristics in bold. As can be seen in the table there were only two significant correlations out of a possible 32 for the present items, one positive and one negative. Of the remaining 88 correlations six were significant, four of which were positive. Overall, 66 of the 120 correlations were positive. (A positive correlation indicates that a higher perception of risk relates to a higher site entry speed.) The same **analysis was conducted using the respondents' estimated site speed. Only three of the correlations** were significant and none of these were for the present characteristics, so these results have not been presented here.

Table 6.13 Correlations between general risk items and observed site entry speeds. Items in bold represent characteristics present on the site

Site characteristic	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Background noise from road works	0.04	0.05	0.05	-0.05	0.05	0.00	0.19	-0.3*
Dust thrown up by cars	-0.12	0.09	-0.10	-0.18	0.04	0.01	0.17	-0.07
Machinery entering and leaving roadway	0.02	0.11	-0.06	-0.17	0.14	-0.05	0.16	-0.21
People working on edge of road	0.22	0.27*	-0.05	-0.06	0.00	0.02	0.09	0.26
Poor visibility through site	0.17	0.23	-0.02	-0.23	0.09	-0.21	-0.02	-0.14
Reduced lane width	0.11	0.03	0.08	-0.05	-0.05	-0.02	-0.12	0.2
Reduced number of lanes	-0.01	0.06	-0.12	-0.27*	0.02	0.04	-0.25	-0.1
Road works wet due to rain	-0.04	0.01	-0.02	-0.07	0.07	0.07	0.32*	-0.36*
Temporary speed limit set too high	0.11	-0.05	0.08	-0.29*	0.05	-0.07	-0.16	0.4
Temporary speed limit set too low	0.1	0.23	0.11	0.00	0.01	0.02	0.15	-0.22
Traffic controlled by stop-go person	0.1	0.14	-0.07	-0.16	0.04	0.08	0.11	-0.20
Traffic delays	0.04	0.27*	-0.12	0.06	0.06	0.12	0.12	-0.21
Traffic diverted into two temporary lanes	0.09	0.31*	-0.10	-0.14	-0.09	0.12	0.01	-0.27

Two lanes merging into one	-0.03	0.13	-0.01	-0.01	0.05	0.02	-0.10	-0.03
Unstable road surface	-0.03	0.15	-0.04	-0.07	0.10	0.03	-0.08	0.23
N	59	62	58	61	54	59	56	49

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6.8.3 Attitudes towards speeding and speed estimates and behaviour

Calculations were made to see if there was any correlation **between the respondents' self**-reported attitudes towards speeding and general driving beliefs, and between their personal speed estimates and actual chosen speeds. The entire sample of speed estimates was used in the analysis, while the sample of actual speeds was divided into those respondents who were observed in a permanent 50km/h zone and those observed in a permanent 100km/h zone. Respondents from site 5, an unrestricted speed zone, were excluded from the analysis due to the nature of the site.

The results are presented in table 6.14. The speed attitude items generally correlated significantly with the estimated speeds and in all but one case were in the expected direction. However, none of the correlations between the attitude items and the actual speeds were significant, and were not consistently in the expected direction.

Table 6.14 Correlations between attitudes to speeding items and estimated and observed site approach speeds, broken down by permanent speed limit

Item	Estimated speed		Actual speed		Expected sign
	50 km/h	100 km/h	50 km/h	100 km/h	
Speed limits should be enforced more strongly	-0.25***	-0.31***	0.04	-0.06	Neg.
Speeding fines are just a way for the government to make money	0.03	0.14**	-0.04	0.05	Pos.
Travelling faster has a minimal effect on how likely people are to be injured in a crash	-0.07	0.02	-0.09	0.04	Pos.
Most permanent speed limits are appropriate for the conditions of the road	-0.13**	-0.12**	0.08	0.06	Neg.
Slower vehicles, such as bicycles and mopeds, have as much right to be on the road as cars	-0.12*	-0.06	-0.10	-0.07	Neg.
It's ok to speed if you have a good car	0.10*	0.19***	-0.04	0.07	Pos.
Modern cars perform best over 100km/h	0.02	0.13**	-0.15	-0.03	Pos.
Urban speed limits in heavily populated areas should be lower than 50km/h	-0.3***	-0.29***	-0.15	-0.07	Neg.
Slower drivers are more likely to cause a crash than faster drivers	0.03	0.09	-0.02	-0.06	Pos.
I am a safer driver than the average driver	-0.12*	-0.05	0.08	-0.02	Neg.
I drive a more powerful car than the average driver	-0.02	0.09	0.02	0.11	Pos.
I am more cautious than the average driver	-0.14**	-0.23***	-0.09	-0.12*	Neg.
How considerate do you feel you are to other drivers	-0.17***	-0.19***	-0.09	-0.04	Neg.
How often do you obey speed limits in general	0.33***	0.39***	0.10	0.13*	Pos.

N	455	456	105	300	
Estimated speed – 50km/h road	-	0.47***	0.02	-	Pos.
Estimated speed – 100km/h road	0.47***	-	-	0.21***	Pos.
N	452	452	104	292	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: Respondents from site 5, an unrestricted speed zone, were excluded from the actual speed 100km/h analysis due to difference in the approach between this site and the other 100km/h sites.

6.8.4 Attitudes to road works and speed estimates and behaviours

Correlations were calculated between the specific road work attitude items, general driving beliefs, and the estimated and actual speeds at the site. Analyses were conducted for each TSL separately, but pooled over visibility condition. The results are presented in table 6.15. Error! Reference source not found. Error! Reference source not found. There were few significant correlations, with only five of the correlations between the items and the actual speeds, and 14 with the estimated speeds, reaching significance. Of the four correlations between estimated and actual speeds one was negative and only one was significant.

Table 6.15 Correlations between attitudes to road works and estimated and observed site entry speeds, broken down by temporary speed limit and pooled over visibility conditions

Item	Temporary speed limit							
	100-70		100-50		100-30		50-30	
	Entry speed		Entry speed		Entry speed		Entry speed	
	Est.	Act.	Est.	Act.	Est.	Act.	Est.	Act.
Road works tend to cause unnecessary delays	0.04	0.00	-0.14	0.11	0.06	0.03	0.05	0.08
The road network should be better maintained	0.01	0.03	-0.08	0.07	0.02	0.03	-0.07	0.26**
After road works are completed my driving experience is usually improved	0.14	-0.03	0.17	-0.01	0.11	-0.05	-0.06	-0.18
Temporary speed limits are often left up for too long after the work is over	0.26**	0.14	0.10	-0.11	0.08	-0.06	0.18	-0.1
The speed limits through road works are generally appropriate for the conditions	-0.26**	-0.07	-0.2*	0.03	-0.21*	-0.07	-0.28**	0.08
Crashes are less likely to occur in a road work area than on a normal road	0.07	-0.06	-0.11	0.06	0.10	0.06	0.00	-0.03
I will avoid driving through road works if I am able to	0.00	0.12	0.00	-0.01	-0.16	-0.07	0.02	0.09
There are not always workers where there are temporary speed limits	0.26**	0.01	0.08	0.07	-0.09	-0.23*	0.16	0.11
How considerate do you feel you are to other drivers	-0.24**	-0.01	-0.15	-0.2*	0.02	0.05	-0.32**	0.02

How often do you drive through road works when work is occurring	0.27**	0.11	0.03	0.09	0.02	0.05	0.04	0.3**
How often do you drive through road works when no work is occurring (eg at night)	0.23*	0.17	0.03	0.00	0.00	0.03	0.01	0.23*
How often do you obey road work speed limits	0.30***	0.18	0.23*	0.13	0.21*	0.21*	0.27**	-0.11
Estimated speed through site	-	0.08	-	0.11	-	0.26**	-	-0.17
Minimum N	119	119	117	118	111	111	102	102

* p < 0.05, ** p < 0.01, *** p < 0.001

6.8.5 Site photograph comparison questions

Each site photograph, except for site 5 (the last site tested), was rated by two groups of respondents: those who were observed at the site where the photograph was taken and those who were not observed at that site. The second group consisted of the respondents who were observed at the following site tested, so respondents from the third site tested also rated the photograph from the second site tested. In the case of the first site where data was collected (site 3), the other photograph was of a work zone at the intersection of Parkside Road and Hutt Park Road, Lower Hutt. Table 6.16 gives the order of the sites tested. The perceptions of those drivers who were observed at a specific site were compared with the perceptions of drivers who were not observed there, resulting in seven sets of comparisons.

Table 6.16 Site testing order and mean site entry speed for all data and for survey respondents specifically

Site testing order	Site number	Site name	Mean entry speed (km/h)	
			Overall	Respondents
1st	3	Greytown	58.8	59.6
2nd	6	Te Horo	29.2	31.9
3rd	7	Cambridge Terrace	45.4	45.4
4th	2	River Road	71.4	70.4
5th	8	Eastern Hutt Road	45.3	46.6
6th	1	Western Hutt Road	63.6	65.0
7th	4	Kaitoke	68.8	68.4
8th	5	Coast Road	39.9	37.6

The seven site-specific risk assessment items were combined into overall site risk scales, one for the observed site and one for the non-observed site. These scales were reliable across sites, with the **Cronbach's alphas ranging from** 0.77 to 0.89 for the non-observed site and from 0.80 to 0.94 for the observed site. Tests of the items 'The road works appear to be active' and 'The temporary speed limit is not appropriate for the conditions of the road' were conducted using Kruskal-Wallis non-parametric tests, while the analyses of the speed estimates and overall site risk scale were conducted using t-tests (see table 6.17). Overall, there were very few differences between the scores of respondents who were observed at a site and the scores of respondents who were not observed there. The main differences were in judgements of speed, with the non-observed respondents giving lower speed judgements.

Table 6.17 Results table for the comparisons of respondents observed at a site and those who were not observed at the same site

Site testing order	Mean scores		SD		Sample size		df	Test
	Observed	Non-observed	Observed	Non-observed	Observed	Non-observed		
1st and 2nd								
Site appears active ^a	57.55	60.42	NA	NA	58	59	1	0.24
Unsuitable TSL ^a	51.80	59.70	NA	NA	52	59	1	1.83
Overall site risk scale	3.62	3.20	1.14	0.91	56	59	113	2.18*
Site entry speed (km/h)								
Self	52.46	45.87	8.54	12.20	57	58	113	3.35**
Average driver	56.94	48.32	10.86	12.67	56	57	111	3.88***
Good driver	50.18	46.95	9.95	12.56	55	55	108	1.49
2nd and 3rd								
Site appears active ^a	60.34	53.35	NA	NA	59	54	1	1.61
Unsuitable TSL ^a	57.29	53.64	NA	NA	56	54	1	0.39
Overall site risk scale	3.46	3.84	1.15	1.08	58	56	112	1.78
Site entry speed (km/h)								
Self	34.04	33.93	8.77	8.68	58	56	112	0.07
Average driver	38.48	39.06	10.61	8.98	56	53	107	0.3
Good driver	33.88	34.44	8.91	9.32	56	53	107	0.32
3rd and 4th								
Site appears active ^a	57.20	60.66	NA	NA	56	61	1	0.33
Unsuitable TSL ^a	59.88	57.25	NA	NA	55	61	1	0.2
Overall site risk scale	2.95	3.41	0.89	1.24	52	60	110	2.24*
Site entry speed (km/h)								
Self	33.26	34.58	7.02	6.81	56	60	114	1.02
Average driver	38.85	39.33	7.55	6.73	54	60	112	0.36
Good driver	34.14	32.31	6.69	6.05	54	60	112	1.53
4th and 5th								
Site appears active ^a	55.07	53.76	NA	NA	61	47	1	0.06
Unsuitable TSL ^a	50.71	59.41	NA	NA	61	47	1	2.25
Overall site risk scale	3.03	3.65	1.42	0.94	61	46	105	2.57*
Site entry speed (km/h)								
Self	71.04	63.46	12.48	14.47	60	47	105	2.91**
Average driver	75.52	69.15	12.48	13.91	60	47	105	2.49*
Good driver	69.39	64.24	11.34	12.78	60	46	104	2.19*
5th and 6th								
Site appears active ^a	57.66	51.98	NA	NA	48	60	1	0.95
Unsuitable TSL ^a	52.31	56.25	NA	NA	48	60	1	0.46
Overall site risk scale	2.64	2.87	1.05	0.96	45	60	103	1.15

Site testing order	Mean scores		SD		Sample size		df	Test
	Observed	Non-observed	Observed	Non-observed	Observed	Non-observed		
Site entry speed (km/h)								
Self	34.24	36.37	8.61	9.26	46	60	104	1.21
Average driver	38.23	40.86	8.87	8.81	46	59	103	1.51
Good driver	32.39	35.00	6.99	9.33	45	59	102	1.57
6th and 7th								
Site appears active ^a	66.56	55.53	NA	NA	60	61	1	3.49
Unsuitable TSL ^a	62.50	57.46	NA	NA	60	59	1	0.71
Overall site risk scale	3.34	3.31	1.11	1.18	60	61	119	0.15
Site entry speed (km/h)								
Self	67.41	61.71	9.66	12.52	60	61	119	2.8**
Average driver	71.25	67.40	13.60	13.47	60	60	118	1.56
Good driver	67.67	63.22	9.61	10.74	59	59	116	2.37*
7th and 8th								
Site appears active ^a	54.85	59.43	NA	NA	60	53	1	0.6
Unsuitable TSL ^a	57.10	56.89	NA	NA	60	53	1	0
Overall site risk scale	3.25	3.03	1.21	0.95	60	53	111	1.08
Site entry speed (km/h)								
Self	54.02	51.28	10.72	9.89	61	53	112	1.41
Average driver	59.75	55.04	11.99	10.84	61	52	111	2.18*
Good driver	54.83	50.35	10.29	8.13	60	52	110	2.53*

* p < 0.05, ** p < 0.01, *** p < 0.001

Note. Items marked with an ^a were tested with Kruskal-Wallis tests. T-tests were used for all other comparisons.

7 Safe speed estimation

7.1 Major safety concerns at road work sites

The following factors are the primary causes of crashes at road work sites and must be considered when setting safe speeds for these locations:

- driver distraction, which can occur while looking for traffic directions or at activities on the side of the road
- reduced vehicle-flow capacity and speed*
- conflicts between construction activities and traffic
- site workers whose lives are in constant danger due to the increased risk of exposure to crashes.

* One of the major safety concerns associated with the work zone is the increased risk when congestion occurs on the approach to the work zone due to reduced road capacity. If the demand is higher than the capacity of a work zone, then a queue of slow-moving or stopped vehicles may extend upstream of the work zone. If drivers are unaware of the queue before they reach its tail, then they may cause rear-end crashes. The high-speed differential between the end of the queue and the approaching traffic also makes it difficult for approaching drivers to observe the speed differentials and safely reduce their speed. If the surface friction is low due to construction dust, loose particles, or soil or surface water on the active lane surface then it will create a greater risk to vehicles approaching and travelling through the site.

According to NCHRP (1996), the following conditions should also be considered when identifying a safe speed for a work site:

- roadside activities approximately 30m from the edge of the road
- shoulder activity approaching an area greater than 0.6m and less than 30m from the edge of the road
- activity area approaching between 0.6m from the edge and the travel lane
- moving activity on the shoulder
- activity area approaching between the centreline and the edge (lane closure)
- activities that require temporary bypass road way
- activities on both sides of the centreline of a road way.

For the first condition in the NCHRP (1996) list, no speed reduction is required. For all the other conditions a speed reduction is necessary, depending on which factors noted in appendix A are involved.

Results from a survey conducted by Maze et al (2000) indicated that 27 agencies supported a speed reduction at the lane shift with only four agencies against it. The lane shift is very similar to a lane crossover median but is less dangerous. Therefore, this variable is also included in section 7.2.1 as a lower priority.

After considering all these factors the following guidelines were prepared.

7.2 Guidelines for estimating safe speeds at a work site

7.2.1 Variable factors

The prioritised variable factors that need to be taken into account when estimating a safe speed for the approach to a work zone are:

- 1 danger to the public or site workers
- 2 skid resistance (if it is not related to new seal)
- 3 loose material on the sealed surface could harm the vehicles or workers
- 4 visibility conditions restricted due to dust or new alignment
- 5 surface friction below the acceptable limit or below that of the adjacent road
- 6 objects or personal equipment that could drop onto the live lane and encroach on traffic flow
- 7 reduced number of lanes
- 8 emergency (eg flood, slips, accidents)
- 9 vehicle stability changes because of road geometry changes due to site work
- 10 temporary roadway
- 11 roadside device (eg guardrail, cones) in narrow lane (if on the right this is a lower priority; if on the left, a higher priority to protect it from being knocked down)
- 12 traffic directed to cross the median
- 13 lane shift
- 14 weather conditions (eg high average wind speed or wind gusts, high levels of precipitation)
- 15 any other matters that affect safety (eg previous crash history, driver expectancy/unexpected condition, presence of pavement edge drop-off, lack of shoulder, pedestrian activity, previous experience with similar work zone).

The following regular road conditions will also need to be accounted for when estimating the safe work site speed limit. If one or more of the following are present then a reduction in speed will be required.

- shoulder width is not within the approved limit (check design speed < temporary speed limit, see table 3.2).
- lane width is narrow compared with adjacent road sections (check design speed < temporary speed limit, see table 3.2).
- new sealing protection (use the appropriate speed from table 2.1).

Section 7.2.2 explains how to account for these factors when estimating the appropriate TSL.

7.2.2 The speed limit estimation procedure

The speed limit procedure outlined here is based on previous research, but has been modified to take into account the findings of the current project. The conditions referred to are the conditions and factors listed above in section 7.2.1.

- If all the conditions are safe then use the existing speed limit.

- If one or more conditions are unsafe then reduce the speed limit by 10km/h for each condition.
- If one or more of the conditions are severe then reduce the speed limit by 20km/h for the first condition and by 10km/h for each of the subsequent conditions.
- If a single severe condition exists then reduce the speed limit by 20km/h.
- If all the conditions are rated as low risk then reduce the speed limit by 20km/h.

The lowest TSL in the study was 30km/h but 20km/h or ‘stop and go’ can be posted in case of an emergency or an unavoidable situation. The limit can be any multiple of 10 within the range of 20 to 80km/h, but must be at least 20km/h less than the existing speed limit on the road.

The final temporary speed should be derived from the flow chart in figure 7.1.

7.2.3 Establishment of reasonable work zone speed limits

Use equation 4 on page 25 to estimate the operating speed at work zones. To estimate the safe speed, first identify the limiting factors and/or conditions from the lists in section 7.2.1 and then follow the procedure described in section 7.2.2. In doing this:

- 1 Check that the variable factors noted in section 7.2.1 exist at the site.
- 2 Detail the characteristics of the site problems in order to reduce or eliminate them.
- 3 Confirm that the speed reduction will improve safety.

The third point is difficult to do in all cases but it can be justified from past experience.

If the safe speed is less than the operating speed then the following options should be considered:

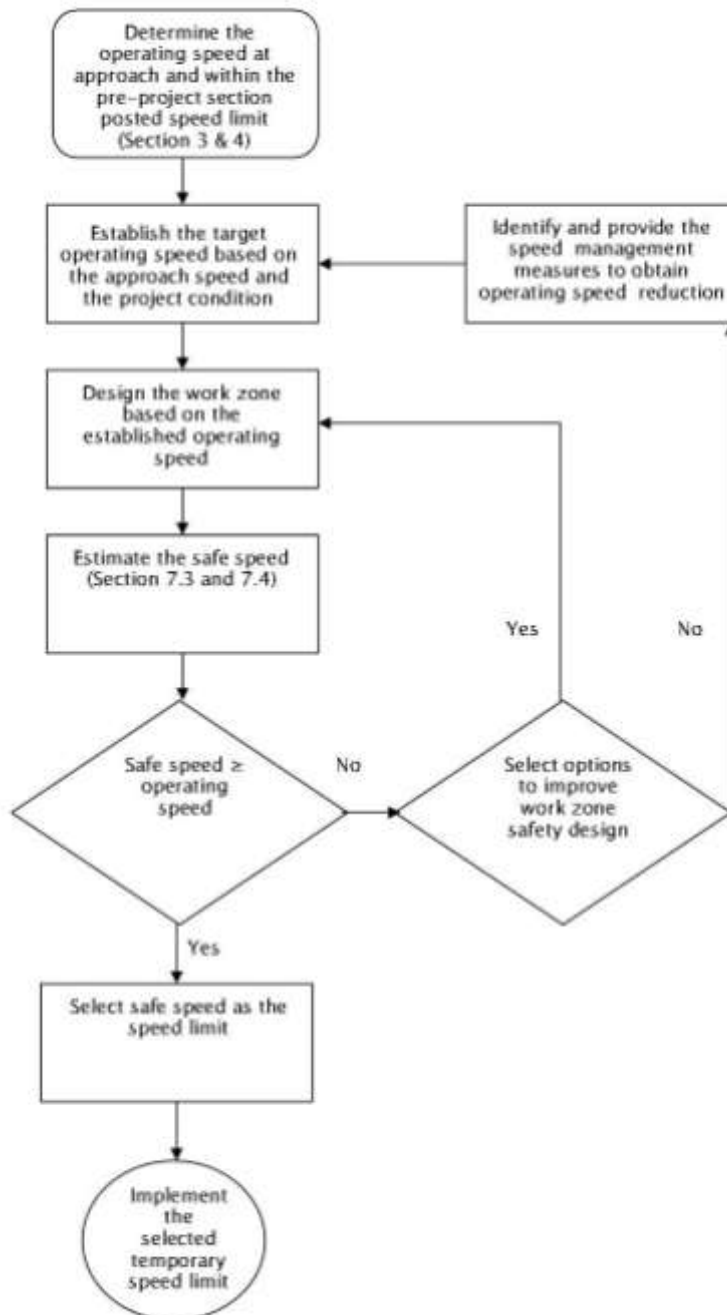
- Improve site safety conditions and re-estimate the safe speed. This process should be continued until the operating speed is equal to or less than the safe speed.
- If improvement is not possible then introduce a traffic management measure to reduce the operating speed until the operating speed is equal to or less than the safe speed. See below for some examples of traffic management measures.

If the safe speed is greater than the operating speed then select the safe speed as the TSL.

The limiting factor or factors of the safe speed can be identified from the safe speed estimation procedure, which is explained in sections 7.2.2 and 7.2.3. The limiting factor or factors need to be either eliminated or reduced to improve the work zone safe speed. According to the improved safe speed the design of the work zone should be revised. If the safety condition of the site cannot be improved then the next option is to introduce positive traffic management measures to reduce the work zone and approach speeds. Traffic management measures, for example speed trailers, warning devices, and physical lane narrowing and visual/optical lane narrowing via side friction, can be used to reduce speed.

Establishing reasonable work zone site-specific speed limits should follow the procedure given in figure 7.1. This flowchart has been slightly modified from the chart given in appendix F.

Figure 7.1 Flowchart for establishing a reasonable work zone site-specific speed limit



8 Discussion

The speed distribution data at the approach to and point of entry at each work zone showed that:

- the 85th percentile speed was considerably higher than the TSL for most sites
- the speed variance increased at the entry point of most work zones.

Migletz et al (1999) demonstrated that the crash rate was lower where the percentage increase in speed variance was lower (see figure 2.1). The above two bullet points indicate an increase in the crash risk at the measured sites. It is important to consider these two points and develop a guide for TSL estimation procedure at work zones in New Zealand if we want to reduce crashes further in the future. The TSL estimation procedure includes estimating appropriate safe speed and operating speeds which will help indicate whether improvements are needed in the site-specific traffic management plan. This will assist the temporary traffic management planner to optimise benefits from the resources used in the traffic management plan. The main benefit from setting appropriate speed limits will be improved safety at sites.

Overall, when considering the 85th percentile speed, which is the operating speed, the research clearly shows that a guideline is needed for TSL estimation in terms of safety. If drivers are not responding to the temporary speed sign, they will retain this bad habit at other traffic control systems in the network and this should be avoided.

As discussed in the research literature, it is important to reduce speed variance, including the mean, at work sites to reduce work zone crashes further.

In the model assessment, actual driver speeds were predicted effectively but accuracy could be improved with further research. The following conclusions were drawn from the model assessment:

- The estimated speed from the model was approximately equal to the measured operating speed at most of the sites except one. However, this site had specific characteristics that were not accounted for in the model (eg excessive dust).
- In two out of eight sites the estimated speed was less than the measured speed. These two sites were influenced by other factors which were not appropriately considered in the model.
- There were no sites at which the estimated speed was substantially less than the measured speed.

Taking the above three points into consideration, the model can be used to estimate the operating speed for the work zone site-specific plan assessment. This will help to identify any need for improvements to site safety or to traffic management plans for determining TSLs (see chapter 7). At this stage the accuracy of predicting an operating speed is good enough to improve the TSL estimation when considering the difference between operating speeds and the existing TSL from all eight sites. The model will help to identify any deficiency in traffic management plans or site design by determining a reasonable TSL.

Headway distance distribution could change with speed distribution at the approach and entry to work zones. Several researchers argued that the headway distance distribution was not a very good measure to assess the crash risk because as the distance between cars decreased, driver concentration increased and accidents were therefore reduced. Arampamoorthy (2005) discussed the potential risks from traffic density and found that crash risks increased up to a certain density level. After that it was not very clear what happened – crash rates either flattened or decreased. This is one reason why we did not investigate headway distribution in this project.

The estimation of safe speed explained in sections 7.2.2 and 7.2.3 is based on international survey data. In a New Zealand situation the driving environment might be different. Although there is room for

improvement in the model the expectation is that the priority factors, set up as outlined, provide a better basis for setting TSLs than not using any model. Additionally, the procedure provides a baseline for future guideline development. The procedure will be discussed with industrial groups and modified if necessary.

8.1 Speed survey results

At all sites the mean site entry speed was significantly lower than the mean approach speeds, indicating that motorists were reducing their speed. However, at all but one site the mean entry speed was significantly higher than the TSL. Within three of the TSL categories significant differences were found for the site visibility condition, both for the mean approach and site entry speeds. Although it was expected that speeds would be higher in the continuous visibility condition this was not the case. In fact, mean speeds were generally higher in the non-continuous visibility condition.

The increased speed variability at the site entry compared with the site approach was due to both slower and faster vehicles (based on approach speeds), with the faster vehicles demonstrating a greater change in variance than the slower vehicles. To reduce the influence of speed variance on crash rates it would therefore seem best to design sites that allow different drivers to travel at similar speeds rather than targeting slower or faster drivers. It should be noted that this is only a basic analysis of one factor potentially related to changes in speed variance. Examining the influence of other characteristics, such as driver age or the presence of passengers, may provide greater insight into the relationship between speed variance and crash rates at work zones, but this is outside the scope of this project.

Mean and 85th percentile speeds were generally higher when no project staff were obviously on site. Speeds ranged from less than 1km/h higher to about 6km/h higher in the off-site condition and they were higher in the on-site condition for one site. While supporting the expectation that vehicle speeds would be higher in the off-site condition, the differences in speeds were generally quite minor (less than 3km/h).

For the three sites tested after the works were completed (sites 4, 7 and 8), speeds were higher after the works than during. This was an intuitive finding, and simply confirmed that the reduction difference in approach and entry speeds was due to the works and not road-specific environmental factors.

At site 3 site speed measurements were taken from two locations, at the taper and about 500m further into the site. While mean speeds were lower at the location further into the site, the difference did not reach statistical significance. The approach speeds which were measured when the TIRTL was positioned further into the site were significantly lower than the approach speeds when the TIRTL was at the start of the taper. This could be due to vehicles generally travelling more slowly. Given that for the other seven sites the works occurred closer to the site entry than for site 3, it is reasonable to expect that there would have been minimal changes in vehicle speeds if the site entry speed measurements were taken in a different location.

Vehicle approach speeds and site entry speeds were significantly and positively correlated for each site, although some correlations were fairly small (range of 0.15 to 0.45). The correlations were also generally higher when only the free-travelling vehicles were considered (range of 0.20 to 0.48). This is consistent with previous research that found positive relationships between repeated measurements of the same vehicles (Haglund and Åberg 2002; Wasielewski 1984). For their studies the vehicles were measured at the same location, whereas for this study they were measured at two different locations.

The repeated measurements from site 5 provided an opportunity to analyse speed data measured at the same location, although the vehicles were measured once in each direction; whereas for Haglund and Åberg (2002) and Wasielewski (1984) all the vehicles were measured travelling in one direction. This

analysis found stronger relationships between speeds measured at the same location (eg at the site) than those measured at the two different locations (ie at the site and approaching the site).

8.2 Driver survey results

Drivers' attitudes towards speeding and general driving attitudes tended to relate significantly to their speed estimates for the 50km/h and 100km/h roads, with the strongest predictor being their self-report on how often they obeyed speed limits in general. The two speed estimates also correlated strongly. However, very few of the attitude items were significantly related to the drivers' observed speeds. This is likely to be due in part to a reduction in sample size, as the total sample was split on the original site speed limit. However, the correlations with the observed speeds were generally quite low, and were often of the opposite sign to the estimated speed correlations. As well, only the estimated speed in a 100km/h area was significantly related to the observed speed, with effectively no relationship between estimated and observed speeds in a 50km/h area. This pattern was repeated for attitudes to road works, although fewer of the attitude items related to the estimated speeds. The sample sizes for the estimated and observed speed correlations were the same, so differences in test power cannot explain this finding. While the relationships between risk and speed attitudes and respondent estimates of speed behaviours matched previous studies (Brown and Cotton 2003; Elliot and Armitage 2006), the general lack of a relationship with observed speeds did not (cf Åberg et al 1997; Corbett 2001; Haglund and Åberg 2000; Warner and Åberg 2006).

For the site-specific risk items there were very few significant correlations with either the estimated or observed speeds. **In only one instance was there a significant relationship between the respondents' estimated and observed speeds.** There was also no consistency in the correlations, most notably in that the signs of the relationships were not consistent across sites.

The general site characteristic analysis matched the other analyses. It was expected that risk perceptions of characteristics that were present at a site would be more strongly correlated with the observed speeds than the perceptions of non-present characteristics. Overall there were very few significant relationships between observed speeds and risk perceptions, regardless of whether the characteristic was present or not. If higher risk perceptions were related to lower speeds in general it would be expected most of the correlations would be negative, even if they were not significant. However, just under half of the correlations were negative, and only four of the eight significant correlations were negative.

Driver speed estimates at the work sites, both for themselves and for an average driver, were generally either fairly accurate (ie there was no significant difference between their estimated and observed speed), or, more often, significantly underestimated. There were only two sites (5 and 6) where the speed of the average driver was significantly overestimated.

These findings match previous research. While many of the studies have found significant relationships between risk perceptions and behaviour (Iversen 2004; Machin and Sankey 2008; Uilleberg and Rundmo 2003, 2004), these studies have used self-reported behaviours rather than objectively measured behaviours. Studies which have compared risk perceptions to objective behaviours have found limited relationships (Farrand and McKenna 2001; Gregersen 1996; Heino et al 1996; Sümer et al 2007).

8.2.1 Implications

The overall results of the survey indicate that the respondents' attitudes and perceptions do not match their actual behaviours, although they may match their personal expectations of their own behaviours. In terms of setting a TSL, it appears that it is not necessary to take into account drivers' subjective

impressions of the road. **This does not mean that the respondents' perceptions did not affect** their behaviours, but rather that the factors the respondents subjectively perceived to be important were not the factors that actually influenced their behaviour. Drivers did reduce speed around the sites, but this decrease was not related to their self-reported perceptions. The main implication of this is that asking people to report on which roading factors influence their driving speeds is likely to result in few practical speed-reduction measures. The focus, then, should be on which environmental factors, such as positive traffic management measures, affect observed driver speeds, and on installing TSL signage.

8.3 Limitations

There was one major limitation to this research. Only eight sites were used for the data collection, with the majority of these being chipsealing sites. Speed control at chipsealing sites is difficult, especially for sites where the sealing work has been completed (eg sites 4, 5 and 7). This means it is not possible to determine exactly how generalisable the findings will be to other types of work sites. However, further research using a wider variety of sites would mitigate this limitation.

Although a general assessment of each site was made to confirm whether they were CoPTTM compliant (see section 5.1), for future research it would be beneficial to engage in a more rigorous process. For instance, each site could be given an informal audit process. Additionally, not obtaining the site TMPs meant that the sites could not be judged in relation to their intended traffic management design, which might have differed from standard CoPTTM. The consequence is that even though the sites appeared compliant on the day of surveying, a detailed measure of the level of CoPTTM compliance could not be included in the speed estimation model. Minor CoPTTM infractions (eg slightly too wide cone spacing) might have a measurable impact on driver speeds, but whether this was the case could not be determined from the data.

8.4 Future research

This section discusses some ideas for future research into improving the speed limit estimation procedure. Drivers may not identify the importance or urgency of speed reduction at a work zone. Driver attention may be distracted by construction activities at any time and this could be another factor towards increasing work zone risk and therefore cannot be neglected. Driver distraction could happen anywhere but the chance of distractions at work zones is higher and difficult to measure, compare or identify after a crash. Driver distraction could be a factor for sudden braking. As ARROWS (1998) noted, sudden braking is dangerous and the related crash could be rear-end. Analysing headway distance will be an aid to measuring the risk within a work zone.

There are several variable factors which limit the safe speed at work zones. The prioritised variables listed in section 7.3 were based on appendix E and general assumptions should be reassessed to improve the safe speed estimation. More variable factors should be added. For example, driver distraction related to work activities at sites needs to be assessed or surveyed by experts and drivers.

The model used in this project predicted the operating speed, which was a variation of up to 15km/h. This estimation was based on the eight sites assessed in the project and could be reduced further. Speed reduction, due to temporary changes such as crossover centreline, lane closure, chipseal, visibility and wet weather conditions, needs to be assessed and evaluated to improve the model further.

Evaluating intelligent speed control methods and the effectiveness they have on mean and variance of speeds should be assessed. If these methods are capable of reducing work zone operating speeds then the possible reduction should be obtained and added to the model (see chapter 4) as another variable.

8.5 Key recommendations

Applying the model outlined in chapter 7 during the site design phase will enable accurate estimates of driver speeds to be made. This process should highlight whether driver speeds will match the desired TSL, and enable changes to be made to the site design before work begins.

There is still room for improvement in the model, as the findings of this study suggest that the model overestimated driver speeds. Additional site factors that influence driver speeds could be determined through extending the research and would enable a more accurate model to be developed. These additional factors should be determined through objective testing at different sites rather than through self-report survey methods, given the lack of relationship between drivers' self-reports of attitudes and perceptions and their actual driving behaviour.

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10 Glossary

Approach speed	Vehicle speeds on the road approaching the work zone
Continuous work zone	The work zone was completely visible to drivers at the start of the site
Design speed	A speed fixed for the design of minimum road geometric
Edge break	Road failure where the edge of the road breaks away
Free travelling vehicle	A vehicles with a headway of at least 6s
Headway	The time interval between the rear of one vehicle passing a specific point and the front of the following vehicle passing the same point.
Maximum safe speed	The upper limit of vehicle speeds that are safe for the prevailing conditions of the road
Mean speed	Mean of the free-travelling speed
Non-continuous work zone or site	The work zone (site) was not completely visible to drivers at the start of the site
Operating speed	85 percentile vehicle free-travelling speed
Plastic or guiding barrier	A plastic wall with variable height, width and length and each part coloured (eg red and white)
Safe speed	Any speed lower than the maximum safe speed
Safety barrier	Steel or concrete barrier used for traffic safety and certified by crash testing, and able to prevent vehicles crossing the centre line.
Speed variance	The variance of the free-travelling vehicle speed
Target operating speed	The operating speed aimed in the design stage of work zone
Temporary speed limit	A speed limit set lower than the original speed limit of a section or sections of road and used primarily around work zones.
85 percentile speed	85 percentile free-travelling speed distribution

Appendix A: Field data sheet

Note: Data from this sheet was used for the modified Benekohal model.

Date:----- Start time :-----
 Finished Time:-----
 City:----- Suburb:----- Road
 Name:-----
 Environment: Urban Rural
 Speed limit:----- Temporary speed:-----
 Location: Start:----- End:----- Direction: Inc,
 Dec
 Weather: Dry, Wet or Overcast Light: Day or Night,
 Police frequency: Low ----- Moderate ----- High-----

Road Geometry

slope: F R M Approach: Straight , Curve Site: Straight , Curve
 Number of Lane in each direction: I ---- D ---- Number of open lanes: I ---- D ---
 -
 Open Lane width at site: ----- Approach Lane width: -----
 Field of view:
 Lateral clear distance Right:----- Left:-----
 See all work zone start to end from 100m away in the approach partly fully
 Surface condition: Rough --- loose material--- Resealed--- smooth----

Work activity

Number of workers present in the active work zone (e.g. 0,1,2,...10,10<): -----
 Number and size of construction equipment Heavy:----- Light:-----

 Noise and vibration condition: High:----- Low:-----
 Dust condition: Clear Average Bad
 Shortest distance between active work area and the open lane:-----
 Work zone duration: ----- Hours / Days / Weeks
 Traffic Management devices (e.g. cones, signs): Acceptable --- Marginal----
 Unacceptable----- (as defined in C20 of the Transit NZ COP for TTM)
 Any other extra activity other than the road works:-----

Appendix B: The letter sent to drivers

Dear <first name>,

Re: Research on Perception of Risk at Road Work Sites

We are currently surveying a select number of motor vehicle drivers in the greater Wellington region. The **purpose of this survey is to examine drivers' perceptions of road works. The vehicle with the licence plate <XXXXXX>** was observed driving near <site> on the <date of testing> and was randomly selected to be included in the study. Your contact details were obtained from the Motor Vehicle Registry and were removed from our files at the time this survey was posted. We have no record of your personal details and will not contact you again.

We ask that the person most likely to be driving on the day indicated please complete the survey. The survey should take about 10 minutes to complete. This is public good research funded by Land Transport New Zealand (<http://www.landtransport.govt.nz>).

We've included the 'Instant Kiwi' to say thanks for taking the time to open this letter. Additionally, the person who completes the survey will be entered into a prize draw to win \$400 worth of MTA vouchers (1st prize of \$200, 2nd prize of \$100, and 3rd and 4th prizes of \$50). Simply fill in the prize draw card and enclose it with the survey.

A postage-paid envelope has been provided so that you can return the completed survey easily and free of charge.

Please return the survey at your earliest convenience. If you have any questions please do not hesitate to contact me.

Kind Regards

Stephen Murray, Ph.D.

Email: Stephen.Murray@opus.co.nz

Tel: +64 4 587 0626

Fax +64 4 587 0604

Note: **If you are under 18, or do not want the 'Instant Kiwi' ticket included, please return the unscratched ticket to us in the same envelope as the prize draw card, including a return address, and we will send you a \$5 gift voucher.**

Appendix C: Driver survey

What this survey is about

The purpose of this research is to examine driver perceptions of various aspects of road work sites. This research has been funded by Land Transport New Zealand (<http://www.ltsa.govt.nz/>) to improve New Zealand's road network. **You don't have to answer any questions that you do not want to.**

IMPORTANT POINTS

1. We value your opinion
2. If a question ***doesn't make sense then let us know, but try to answer by choosing the most*** appropriate response
3. We will not ask you to identify yourself for the survey, so your answers are entirely confidential
4. You may withdraw your participation at any point

This survey should take about 10-15 minutes

Note: Some of the questions ask you to look at some photographs. These photographs are on the other side of this page.



Perceptions of Road Works

For Information Contact
Opus International Consultants
Stephen Murray: Ph 04 5870626 or email stephen.murray@opus.co.nz
Freeport 159581, Opus Central Laboratories, PO Box 30845, Lower Hutt

Please tick the box that you feel most suits your opinion of the following statements.	Strongly disagree	Disagree	Not sure/Neutral	Agree	Strongly agree
1. Speed limits should be enforced more strongly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. Road works tend to cause unnecessary travel delays	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. Speeding fines are just a way for the government to make money	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. The road network should be better maintained	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5. I am a safer driver than the average driver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. After road works are completed my driving experience is usually improved	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7. Travelling faster has a minimal effect on how likely people are to be injured in a crash	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8. I drive a more powerful car than the average driver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9. Temporary speed limits are often left up for too long after the work is over	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10. Most permanent speed limits are appropriate for the conditions of the road	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. Please indicate how considerate you feel you are to other drivers? <i>[Please place an X on the line]</i>	
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">0</div> <div style="flex-grow: 1; border-bottom: 1px solid black; position: relative;"> <div style="position: absolute; left: 0; top: -5px;">Inconsiderate</div> <div style="position: absolute; right: 0; top: -5px;">Considerate</div> </div> <div style="margin-left: 10px;">6</div> </div>	
12. Please indicate how considerate you feel the average driver is to other drivers? <i>[Please place an X on the line]</i>	
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">0</div> <div style="flex-grow: 1; border-bottom: 1px solid black; position: relative;"> <div style="position: absolute; left: 0; top: -5px;">Inconsiderate</div> <div style="position: absolute; right: 0; top: -5px;">Considerate</div> </div> <div style="margin-left: 10px;">6</div> </div>	
13. Please indicate how considerate you feel a good driver is to other drivers? <i>[Please place an X on the line]</i>	
<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">0</div> <div style="flex-grow: 1; border-bottom: 1px solid black; position: relative;"> <div style="position: absolute; left: 0; top: -5px;">Inconsiderate</div> <div style="position: absolute; right: 0; top: -5px;">Considerate</div> </div> <div style="margin-left: 10px;">6</div> </div>	

Please indicate the speeds you feel the following drivers would travel on a 100 km/h road in good driving conditions. <i>[Your best guess is fine]</i>		
14. Yourself _____ km/h	15. An average driver _____ km/h	16. A good driver _____ km/h

Please indicate the speed you feel the following drivers would travel on a 50 km/h road in good driving conditions. <i>[Your best guess is fine]</i>		
17. Yourself _____ km/h	18. An average driver _____ km/h	19. A good driver _____ km/h

Please indicate how often you do the following activities.	Never	A few times a year	A few times a month	A few times a week	Most days	Daily
20. Drive on the open road / motorways	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21. Drive through road works when work is occurring	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22. Drive through road works when no work is occurring (e.g. at night)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please tick the box that you feel most suits your opinion of the following statements.	Strongly disagree	Disagree	Not sure/ Neutral	Agree	Strongly agree
23. The speed limits through road works are generally appropriate for the conditions	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
24. Slower vehicles, like bicycles and mopeds, have as much right to be on the road as cars	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
25. Crashes are less likely to occur in a road work area than on a normal road	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
26. I will avoid driving through road works if I am able to	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
27. It's ok to speed if you have a good car	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
28. I am a more cautious driver than the average driver	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
29. Modern cars perform best at speeds over 100 km/h	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
30. There are not always workers where there are temporary speed limits	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
31. Urban speed limits in heavily populated areas should be lower than 50 km/h	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
32. Slower drivers are more likely to cause a crash than faster drivers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please tick the box that you feel most accurately answers the following questions. [Your best guess is fine]	Always	Usually	Sometimes	Rarely	Never
33. How often do you obey road work speed limits?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
34. How often do you think most people obey road work speed limits?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
35. How often do you think a good driver would obey road work speed limits?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
36. How often do you obey speed limits in general?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
37. How often do you think most people obey speed limits in general?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
38. How often do you think a good driver would obey speed limits in general?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please look at Photograph 1 before answering questions 39 – 50

Please indicate how likely you think each of the following occurrences is when travelling through the road works pictured in Photograph 1 [Please place an X on the line]		
39. Loose stones chip the windscreen	Low likelihood	High likelihood
40. Dust impairs vision	Low likelihood	High likelihood
41. A motorist collides with road working machinery	Low likelihood	High likelihood
42. Vehicles will take longer to stop	Low likelihood	High likelihood
43. A road worker is injured by a passing motorist	Low likelihood	High likelihood
44. Two motorists collide	Low likelihood	High likelihood
45. A motorist is injured	Low likelihood	High likelihood

Please indicate the speed you feel the following drivers would travel through these road works <i>[Your best guess is fine]</i>		
46. Yourself _____ km/h	47. An average driver _____ km/h	48. A good driver _____ km/h

Please tick the box that you feel most suits your opinion of the following statements in relation to Photograph 1.	Strongly disagree	Disagree	Not sure/Neutral	Agree	Strongly agree
49. The road works appear to be active	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
50. The temporary speed limit is not appropriate for the conditions of the road	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Please look at Photograph 2 before answering questions 51 – 62

Please indicate how likely you think each of the following occurrences is when travelling through the road works pictured in Photograph 2 <i>[Please place an X on the line]</i>		
51. Loose stones chip the windscreen	Low likelihood	High likelihood
52. Dust impairs vision	Low likelihood	High likelihood
53. A motorist collides with work zone machinery	Low likelihood	High likelihood
54. Vehicles will take longer to stop	Low likelihood	High likelihood
55. A road worker is injured by a passing motorist	Low likelihood	High likelihood
56. Two motorists collide	Low likelihood	High likelihood
57. A motorist is injured	Low likelihood	High likelihood

Please indicate the speed you feel the following drivers would travel through these road works <i>[Your best guess is fine]</i>		
58. Yourself _____ km/h	59. An average driver _____ km/h	60. A good driver _____ km/h

Please tick the box that you feel most suits your opinion of the following statements in relation to Photograph 2.	Strongly disagree	Disagree	Not sure/Neutral	Agree	Strongly agree
61. The road works appear to be active	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
62. The temporary speed limit is not appropriate for the conditions of the road	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Ignoring the photos, please indicate how much you think the following aspects of road works affect the likelihood of a crash occurring <i>[Your best estimate is fine. Please place an X on the line]</i>		
	Much Less Likely	Much More Likely
63. People working on the edge of the road.	0 1 2 3 4 5 6	
64. Two lanes merging into one	0 1 2 3 4 5 6	
65. An unstable road surface such as gravel	0 1 2 3 4 5 6	
66. Reduced lane width	0 1 2 3 4 5 6	

Ignoring the photos, please indicate how much you think the following aspects of road works affect the likelihood of a crash occurring [Your best estimate is fine. Please place an X on the line]			
	Much Less Likely	No Change	Much More Likely
67. A reduced number of lanes on a multilane street	0 1 2 3 4 5 6		
68. Poor visibility through the work area	0 1 2 3 4 5 6		
69. The temporary speed limit set too low	0 1 2 3 4 5 6		
70. The temporary speed limit set too high	0 1 2 3 4 5 6		
71. Traffic controlled by a stop / go person (i.e. one lane only)	0 1 2 3 4 5 6		
72. Dust thrown up by cars	0 1 2 3 4 5 6		
73. The road work area being wet due to rain	0 1 2 3 4 5 6		
74. Traffic delays (e.g. queues)	0 1 2 3 4 5 6		
75. Background noise from the road works	0 1 2 3 4 5 6		
76. Machinery entering and leaving the roadway	0 1 2 3 4 5 6		
77. Through traffic diverted into two temporary lanes, including the shoulder	0 1 2 3 4 5 6		

78. How many years have you been driving motor vehicles?											
<input type="checkbox"/> I don't drive a motor vehicle	<input type="checkbox"/> Less than 1 year	<input type="checkbox"/> 1-3 years	<input type="checkbox"/> 3-5 years	<input type="checkbox"/> 5-7 years	<input type="checkbox"/> 7-9 years	<input type="checkbox"/> 9-11 years	<input type="checkbox"/> 11-13 years	<input type="checkbox"/> 13-15 years	<input type="checkbox"/> 15-17 years	<input type="checkbox"/> 17-19 years	<input type="checkbox"/> More than 19 years

79. What is your highest educational qualification?	80. Please indicate your current personal income	81. Please indicate your age group	82. What type of private car driver's license do you have?
<input type="checkbox"/> Fifth Form Qualification	<input type="checkbox"/> \$15,000 or less	<input type="checkbox"/> 17-24	<input type="checkbox"/> None
<input type="checkbox"/> Sixth Form Qualification	<input type="checkbox"/> \$15,001-\$30,000	<input type="checkbox"/> 25-34	<input type="checkbox"/> Learners
<input type="checkbox"/> Higher School Qualification	<input type="checkbox"/> \$30,001-\$50,000	<input type="checkbox"/> 35-44	<input type="checkbox"/> Restricted
<input type="checkbox"/> Bachelor degree	<input type="checkbox"/> \$50,001-\$70,000	<input type="checkbox"/> 45-54	<input type="checkbox"/> Full
<input type="checkbox"/> Higher degree	<input type="checkbox"/> \$70,001-\$100,000	<input type="checkbox"/> 55-64	
<input type="checkbox"/> Other post-school qualification	<input type="checkbox"/> \$100,001 or more	<input type="checkbox"/> 65-74	
<input type="checkbox"/> None of the above		<input type="checkbox"/> 75+	
<input type="checkbox"/> Other _____			

83. Please tick the box that best describes your current occupation		
<input type="checkbox"/> In full-time paid employment	<input type="checkbox"/> In part-time paid employment	<input type="checkbox"/> Part-time self-employed
<input type="checkbox"/> Full-time self-employed	<input type="checkbox"/> Caregiver for family or household	<input type="checkbox"/> High school student
<input type="checkbox"/> Tertiary student	<input type="checkbox"/> Sickness or ACC beneficiary	<input type="checkbox"/> Unemployed
<input type="checkbox"/> Retired	<input type="checkbox"/> Other (please specify) _____	

84. Please indicate your gender	<input type="checkbox"/> Male	<input type="checkbox"/> Female
85. How long did it take you to fill out this survey? [approximately]	_____ mins	
86. How difficult was this survey?	<input type="checkbox"/> Very easy	<input type="checkbox"/> About right
	<input type="checkbox"/> Very hard	

Appendix D: Site photographs used for survey

Site 0 - Used to provide a second photo for the first tested site (Site 3, Greytown)



Testing order 1st - site number 3 (Greytown: start of taper)



Testing order 1st – site 3 (Greytown: middle of work zone)



Testing order 2nd – site 6 (Te Horo)



Testing order 3rd – site 7 (Cambridge Terrace)



Testing order 4th – site 2 (River Road)



Testing order 5th – site 8 (Eastern Hutt Road)



Testing order 6th – site 1 (Western Hutt Road)



Testing order 7th – site 4 (Kaitoke)



Testing order 8th – site 5 (Coast Road)



Appendix E: Factors involved in determining the temporary speed limit

The frequency-specific site factors were reported by 37 state highway agencies in the United States as being used to establish TSLs (extracted from NCHRP 1996).

Factors	Frequency
Lane width	16
Alignment	14
Type of work zone	12
Sight distance	10
Prevailing speed	9
Workers present	8
Accident experience	7
Presence of barrier	7
Roadway type	7
Driver expectancy/unexpected condition	5
Traffic volume	5
Presence of pavement edge drop-off	4
Congestion	3
Construction equipment movement	3
Design speed	3
Engineering judgment	3
Road surface condition	3
Duration of work	2
Existing speed limit	2
Lack of shoulder	2
Pedestrian activity	2

Factors	Frequency
Presence of equipment	2
Approach speed	1
Distance from traffic to workers	1
Distance to barrier	1
Distance to work area	1
Erratic manoeuvres	1
Lack of complain with flagger	1
Length classification of road way	1
Night classification of road way	1
Night construction	1
Number of lanes	1
Other safety-related factors	1
Physical conditions	1
Preconstruction speed limit	1
Presence of flagger	1
Road side development/driveway access	1
Road side conditions	1
Temporary signalisation	1
Undesirable working condition	1
Vehicle mix (trucks)	1
Previous experience with similar work zone	1

Appendix F: Flowchart for temporary speed decision process (extracted from NCHRP 2007)

