Research to support the application of a risk-based approach to temporary traffic management

May 2023

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Waka Kotahi NZ Transport Agency research report 708

Contracted research organisation – WSP New Zealand Ltd

WAKA KOTAHI NZ TRANSPORT AGENCY

New Zealand Government

ISBN 978-1-99-106822-4 (electronic)
ISSN 2815-8377 (electronic)

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Thomas, J. A., Tate, F., Frith, B., Malcolm, L. A., Burton, J., Thomas, F., & Gordon, R. (2023). *Research to support the application of a risk-based approach to temporary traffic management* (Waka Kotahi NZ Transport Agency research report 708).

WSP NZ was contracted by Waka Kotahi NZ Transport Agency in 2022 to carry out this research.

Keywords: risk, risk-based approach, road safety, temporary traffic management, worker safety, workplace culture

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Acknowledgements

We would like to thank the following people for their contribution to this research.

The members of the steering group for their knowledge, guidance and input throughout the project:

- Malcolm Menzies, Waka Kotahi Research Owner
- Ryan Cooney, Waka Kotahi
- Ryan Sutherland, Waka Kotahi
- Hugh Mazey, Ministry of Transport
- Ben Burrows, Higgins
- Brendon French, Waka Kotahi
- Dave Vakameilalo, Waka Kotahi
- John Baille, Waka Kotahi

For support and insights in the site evaluation guidance development workshop and think tank:

- Betty Mitrova and Rachel Robertson, Downer Group NZ
- Jo Prigmore and Paul Tyson, Fulton Hogan
- Bruce Claypole and Tom Kiddle, Auckland Transport
- Chris Kerr, Heb Construction
- Dave Adams, Higgins
- Stacy Goldsworth, Civil Contractors New Zealand
- Danny Wood, Waka Kotahi

We thank our peer reviewers for their relevant and constructive feedback:

- Dan Sullivan, Solutions in Transport
- Chris Peace, Victoria University of Wellington.

Finally, thanks to the interviewees and survey respondents for taking the time to contribute to this work.

Abbreviations and acronyms

AADT	annual average daily traffic
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ANOVA	Analysis of variance
CAS	Crash Analysis System
CCT	customer communication terminal
CCTV	closed-circuit television
CS	conflicting speed
DOT	Department of Transport
ETSC	European Transport Safety Council
HRS	Highway Resource Solutions
IPV	impact prevention vehicle
MIRi	Measurement of Injury Risk [Index]
MTC	manual traffic controller
NCHRP	National Cooperative Highway Research Program
OSSR	offside signs removal
PCBU	Person Conducting a Business or Undertaking
PIARC	World Road Association
PPE	personal protective equipment
PSA	portable site alarm
RCA	road controlling authority
STMS	Site Traffic Management Supervisor
TA	time to accident
TCT	traffic conflicts technique
TMP	traffic management plan
TRL	Transport Research Laboratory
TSL	temporary speed limit
TTC	time to collision
TTM	temporary traffic management
UFOV	useful field of view

Contents

Executive summary

Working on or near roads is a recognised high-risk activity. Temporary traffic management (TTM) is used to protect road workers from road users, to protect road users from any hazards related to the work site, and to reduce disruption to traffic flows during works.

In Aotearoa New Zealand there is a shift in the approach to TTM from the Code of Practice for Temporary Traffic Management to a more risk-based approach. To support that move and ensure that the risk-based approach is successfully adopted, information about the risk-based approach must be readily available to help those implementing TTM to determine the best TTM solution based on identified risks/hazards.

This research reviewed international and national published research and grey literature around solutions that help solve risk-based safety concerns at TTM sites. This review was then used to inform the development of site evaluation guidance material and a 60-second tool. The site evaluation guidance was aimed at creating a consistent approach to evaluate and report on TTM case studies (monitoring the success of new and existing setups). The 60-second tool was designed to test whether the TTM plan will work once at site and to identify any new on-site information about the setup or conditions that may alter the risk profile. A co-development approach was used for the creation of the guidance and tool. This included a workshop and think tank, resulting in a format that is relatable and applicable for those using it.

In addition, the literature review and 11 semi-structured interviews with those involved in the TTM process provided the basis for the development of a survey to identify attitudes, behaviours and perceptions of people planning, undertaking and managing the risk of working near live traffic. The survey was distributed through convenience sampling via multiple channels. A total of 316 TTM workers provided responses about safety culture, the risk-based approach to TTM, and complex sites, including near misses at complex sites. Key findings from this survey are listed below.

Safety culture

- 1 in 4 people believe risk around live traffic is a part of the job.
- Around half of people believed that safety on site was traded off against competing needs like cost and traffic flow.
- 2 out of 3 people feel empowered to actively make changes to improve safety.

The risk-based approach to TTM

- 9 out of 10 people have some confidence in their understanding of the controls in a risk-based approach.
- 6 in 10 people are willing to adopt the risk-based approach.

Complex work sites

- 1 in 4 people indicated that workers did not always use full personal protective equipment (PPE).
- Only half of workers always had a spotter when needed.
- 1 in 4 people indicated that unsafe work vehicle movements are occurring.
- Workers say that public drivers are not following the speed limit at work sites.
- Over half of respondents experienced aggression or abuse from other road users.
- 2 in 5 workers reported other road users had trouble navigating the site.

Near misses at complex work sites

- Near misses are occurring, with 2 out of 3 people observing or hearing about a near miss at the last complex site they worked on.

- Sites with single-lane alternating flow setups (stop/go with either manual traffic controllers or portable traffic lights) had the highest rate of near misses, while sites with reduced lane width had the lowest rate of near misses.

Recommendations

The following recommendations have been put forward for consideration around the risk-based safety solutions (identified from the literature) as well as governance, contracting and monitoring (based on the survey and workshop insights).

Risk-based safety solutions for TTM

1. Enable the use of the wider set of tools available to avoid and reduce exposure to risk, including:
   a. strategically planning roadworks to ensure worker safety is considered at all stages of the life cycle of any road-related works projects (including long, medium or short-term works)
   b. having processes that require opting out of the more effective risk-based controls like elimination (eg, through road closures) or isolation (eg, physical barriers), as opposed to opting in
   c. using traffic demand management techniques to reduce traffic volumes through work sites (particularly relevant for sites with advanced planning phase)
   d. providing better quality information to drivers about site characteristics (risk is reduced if all aspects of the site relevant to driver behaviour and decision making as they approach the site are effectively communicated)
   e. identifying, evaluating and using site layouts that reduce workers crossing live lanes of traffic (eg, sign simplification techniques)
   f. digitising TTM using sensor technology where appropriate (eg, instantly relay any cone or barrier strikes to controllers), which reduces the need for routine inspections (and improves safety monitoring data; further research would be beneficial around the use of this technology).
2. Organise an annual, independent review of TTM sites and solutions to identify:
   a. the rate of use of risk-based controls (ie, elimination, minimisation, administrative control measures and PPE)
   b. opportunities for higher controls within this hierarchy
   c. mechanisms to share this knowledge.
3. Consider use of speed camera enforcement where speed limits and speed reduction techniques (such as traffic calming and speed feedback) are not effective.
4. Review TTM solutions for adaptation in poor visibility conditions, particularly night conditions (considering factors such as glare and wet nights).

Governance

5. Establish a TTM solution evaluation sub-group, the duties of which would include:
   a. identifying sources of competitive funding and processes for looking after this funding
   b. building minimum monitoring requirements (following evaluation guidance from this report) into evaluation funding
   c. administering the evaluation case studies at a national level, including delivery of practice notes and communications back to industry
   d. identifying incentives for innovations that aim higher up the hierarchy of controls
   e. developing TTM staff capability, with pathways to developing technical evaluation competency

f. establishing and monitoring TTM evaluation performance indicators, reporting back to the Road Worker Safety Governance group annually.

Contracting

6. Change language in contracts to include collection and analysis of data to feed into evaluation case studies, especially around larger contracts and alliances (eg, the New Zealand Upgrade Programme, alliance contracts, network outcome contracts).
7. Change language in contracts to include capability building around evaluation and demonstrating evidence of this responsibility within key contractor roles.
8. Develop a competitive research allocation in Waka Kotahi to ensure a diverse range of sites and solutions are covered (ie, not just those from larger alliances).

Monitoring

9. Develop, and agree to use, a consistent industry definition for:
   a. serious near misses (including cause typologies and movement types)
   b. TTM site classification codes
   c. other relevant condition data that will be analysed and reported on by industry.
10. Continue monitoring industry perceptions, culture, and serious near misses (especially causes) annually for comparison with the baseline survey data captured from this study.
11. Enable open, consistent sharing of data from on-site safety tools.

Abstract

As roads are improved and maintained, temporary traffic management (TTM) is needed to protect road workers and road users in this high-risk environment. The purpose of this research was to ensure that the move to a more risk-based approach, with a wider set of controls to manage risk exposure to improve TTM safety, is backed by evidence.

The three main phases of this work included a literature review of solutions to help solve safety concerns at TTM sites; a workshop and think tank to co-develop guidance material for a practical, consistent data capture approach to support evaluation of TTM solution trials; and expert interviews and an industry survey to understand the attitudes and behaviours of people planning and managing risk when working near live traffic, including the capture of unique near-miss data.

Key outputs included guidance to better capture case studies and lessons around TTM solutions, and a 60-second tool to evaluate changes to risk on site. We found that existing evaluation is limited and often focuses on speed alone. Consequently, there is an opportunity to use a wider set of metrics (like worker exposure hours) to match the available set of risk-based controls, and to invest in industry monitoring capability to improve TTM safety. We recommend that TTM solutions that reduce exposure to risk be considered earlier in the process and be enabled by the contracting process.

1 Introduction

Working on or near roads is a recognised high-risk activity. Temporary traffic management (TTM) is used to:

- protect road workers from road users
- protect road users from any hazards related to the work site
- reduce disruption to traffic flows during the work.

The operation of TTM in New Zealand is subject to a zero-harm approach. The basis for this is twofold:

1. Waka Kotahi NZ Transport Agency's Safe System approach to road safety as part of the Vision Zero strategy to eliminate traffic-related fatalities and serious injuries
2. the WorkSafe Mahi Haumaru Aotearoa vision for zero workplace harm.

This means that TTM must be set up so that both road workers and other road users are protected. These two goals are synergistic as often measures to protect one will also protect the other. This is because any collision, or near miss between two parties (eg, a conflict between a vehicle and a road worker in a live lane), is potentially hazardous to both parties.

In New Zealand there is a shift in the approach to TTM from the Code of Practice for Temporary Traffic Management to a more risk-based approach. In the context of TTM, Waka Kotahi (2022, para. 13) defines a risk-based approach as 'designing your traffic management plan to consider the risks to people first and then designing the plan to take the best action to keep people safe'. In supporting that move and to ensure that the risk-based approach is successfully adopted, information must be readily available to help those implementing TTM to determine the best TTM solution based on their risks/hazards.

One way of accomplishing this is using guidance and an evaluation framework to provide a consistent approach to evaluating, reporting and presenting case studies where new and existing TTM solutions are trialled under the risk-based approach. To achieve this, guidance needs to include:

- success metrics that allow for difference in context and other factors that will vary across sites
- examples from case studies where new and existing TTM solutions are trialled
- a database ready for populating with ongoing case studies
- input from industry to inform the guidance development process.

Since this consistent approach does not currently exist in New Zealand, this research addresses that gap by developing guidance and a framework for collecting case study data to establish and support evaluating, reporting and presenting case studies that trial TTM solutions.

Furthermore, this research serves to fill the knowledge gap around New Zealand in workers' perceptions, attitudes and safety behaviours when people are planning, undertaking and managing the risk of working near live traffic.

Internationally, perceptions, attitudes and safety behaviours around TTM have been investigated to varying degrees (Benekohal et al., 1995; Haworth et al., 2002; Maze et al., 2000). However, there is not a clear understanding or consistent measure in New Zealand that can be repeated over time to identify trends and changes in industry perceptions. This research is the first step in improving this through developing a baseline survey, applying this at all levels of TTM workers, and reporting on outcomes in four important areas:

1. safety culture
2. the risk-based approach to TTM

3. complex site details
4. near misses at complex sites.

The outputs of this research are a critical part of the broader Road Worker Safety Improvement Programme to support the New Zealand guidance to TTM (as shown in Figure 1.1), providing advice and measuring the effectiveness of devices and controls.

1.1 Purpose

The purpose of this research was to ensure that any move to a risk-based approach to TTM is backed by evidence. This was accomplished by:

- providing an evidence base, from international and national published research and grey literature (eg, working papers, newspaper articles, white papers)
- developing guidance to ensure that TTM provisions for road worker safety under a risk-based approach can be evaluated.

1.2 Research objectives and report structure

This research had four main objectives, each of which is addressed in specific sections of this report (see Table 1.1).

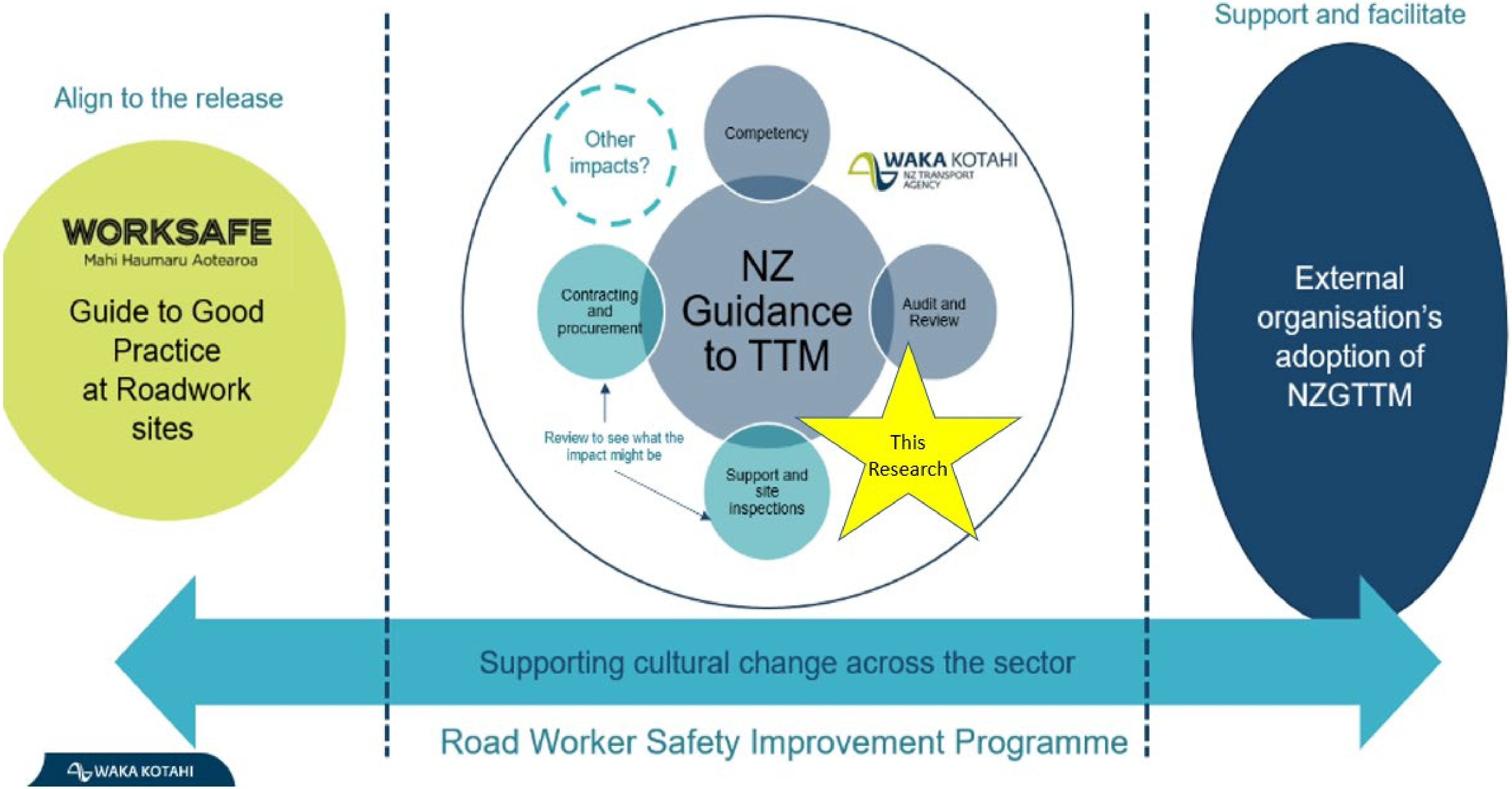
For ease of understanding, each individual section contains the method and results associated with that section. Chapter 6 contains a discussion of the full research, final conclusions, recommendations, and limitations.

Table 1.1 Research objectives and method applied

Objective	Chapter/ Section	Method
1. Review international and national published research and grey literature[a] around solutions that help solve risk-based safety concerns at TTM sites.	2	Literature review
2. Create guidance material and a tool to establish and support a consistent approach to evaluating TTM solutions under a risk-based approach.	3.2	Workshop
	3.3	Think tank
3. Present the results in a relatable, applicable way that can be used as a blueprint for the future.	3.4	Site evaluation guidance
	3.5	Example case study
	3.6	60-second tool
4. Identify attitudes, behaviours and perceptions of people planning, undertaking and managing the risk of working near live traffic	4	Interviews
	5	Survey

[a] Grey literature refers to print or electronic literature that is produced by government, academia, business and industry, and is not controlled by commercial publishers (Auger, 1998).

Figure 1.1 This research within the wider Road Worker Safety Improvement Programme



Note: NZGTTM = *New Zealand Guide to Temporary Traffic Management*

1.3 Scope

The research scope included:

- reviewing international and national research to identify solutions that help solve risk-based safety concerns in TTM sites, including peer-reviewed published reports, industry best practice and grey literature
- capturing attitudes, behaviours and perceptions of people working in TTM through expert interviews and a baseline survey of people working in the TTM industry
- developing site evaluation guidance material and a 60-second tool to establish and support a consistent approach to evaluating, reporting and presenting case studies that trial new TTM solutions
- identifying ambiguity in understanding the scope of the guidance material.

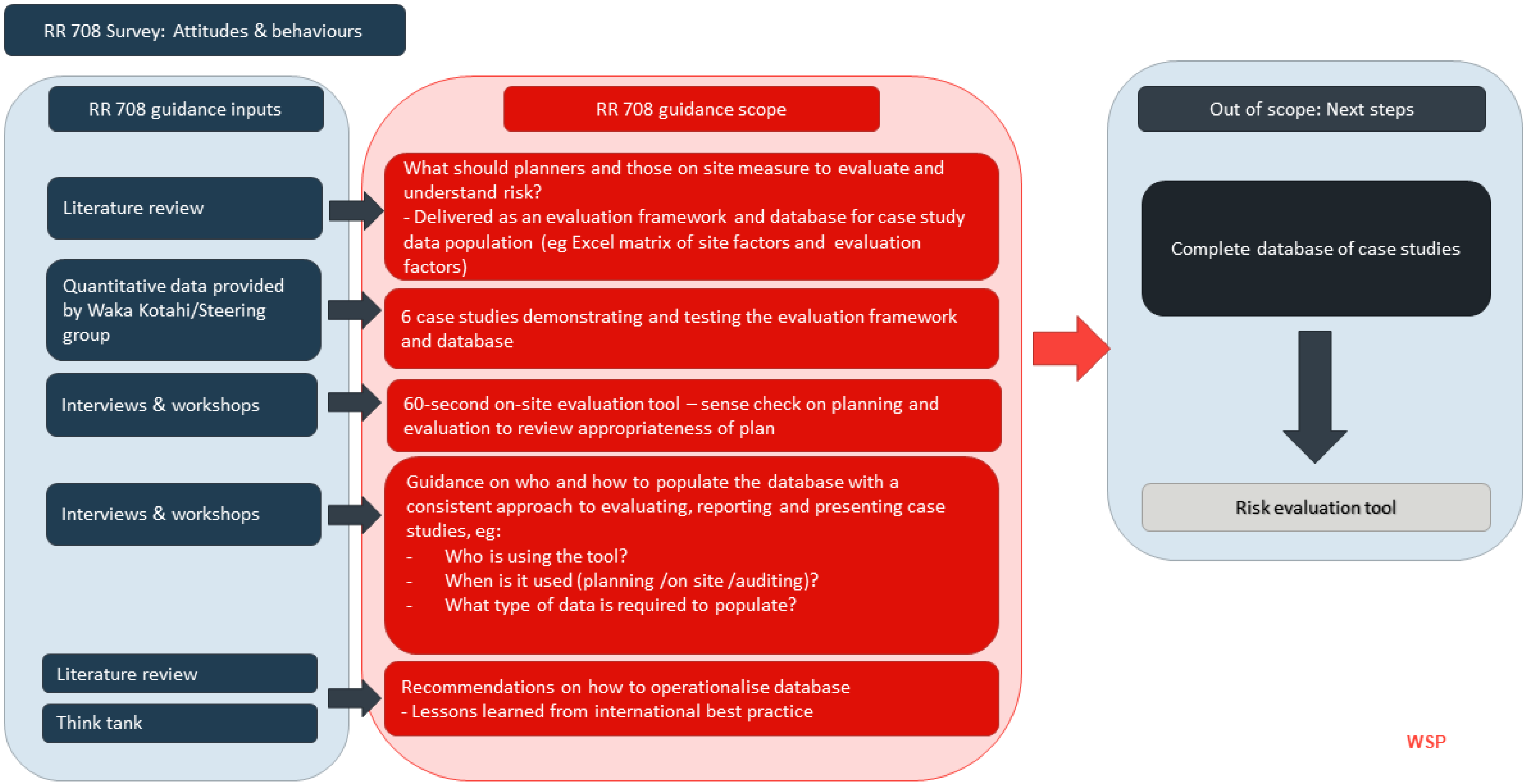
Figure 1.2 provides clarification of the guidance scope and was agreed with the steering group and shared when required with stakeholders throughout the project.

1.4 Outside scope

While the output of this research is an evaluation framework and database, this research had no intentions to fully populate the database with data from case studies. It is expected that, with use and input from the industry, case study data population will be ongoing, with the database providing the blueprint for the final use risk evaluation tool.

The researchers recognise that there is not a consistent definition of risk (see section 1.5) – however, evaluation of the intricacies of this definition are outside the scope of this research.

Figure 1.2 Site evaluation guidance clarification of inputs, scope and next steps (out of scope)



1.5 Definitions

The definitions of 'near miss' and 'serious near miss' were discussed and agreed upon with the project steering group as these were presented along with the hierarchy of controls to the wider TTM workforce in the survey component of this research.

The following definitions have been applied in this research.

1.5.1 Hazard and risk

WorkSafe Mahi Haumaru Aotearoa (2020) provides a definition of both hazard and risk:

> **Hazard:** *Anything that can cause harm. Under HSWA* [Health and Safety at Work Act 2015]*, hazard is defined as 'includes a person's behaviour where that behaviour has the potential to cause death, injury, or illness to a person (whether or not that behaviour results from physical or mental fatigue, drugs, alcohol, traumatic shock, or another temporary condition that affects a person's behaviour)'.*
>
> **Risks:** *Arise from people being exposed to a hazard (a source of harm).*

However, Fowler et al. (2011) used the following definition of risk, which is most relevant to this research as it widens the definition to include probability or exposure, although we recognise that there are many alternative definitions:

> *The probability or exposure to a hazard, combined with the consequences of such exposure.* (p. 27)

1.5.2 Risk-based approach

In the context of TTM, Waka Kotahi (2022) defines a risk-based approach as:

> *Designing your traffic management plan to consider the risks to people first and then designing the plan to take the best action to keep people safe.* (para. 13)

1.5.3 Hierarchy of controls

Section 30 of the Health and Safety at Work Act 2015 states for the management of risks, the Act requires a person:

> *(a) to eliminate risks to health and safety, so far as is reasonably practicable; and*
>
> *(b) if it is not reasonably practicable to eliminate risks to health and safety, to minimise those risks so far as is reasonably practicable.*

This is achieved through the hierarchy of control measures listed in section 6 of the Health and Safety at Work (General Risk and Workplace Management) Regulations 2016, which states:

> *(1) This regulation applies if it is not reasonably practicable for a PCBU* [Person Conducting a Business or Undertaking][1] *to eliminate risks to health and safety in accordance with section 30(1)(a) of the Act.*
>
> *(2) A PCBU must, to minimise risks to health and safety, implement control measures in accordance with this regulation.*

[1] For more information see https://www.worksafe.govt.nz/managing-health-and-safety/getting-started/understanding-the-law/primary-duty-of-care/who-or-what-is-a-pcbu/

(3) *The PCBU must minimise risks to health and safety, so far as is reasonably practicable, by taking 1 or more of the following actions that is the most appropriate and effective taking into account the nature of the risk:*

(a) *substituting (wholly or partly) the hazard giving rise to the risk with something that gives rise to a lesser risk:*

(b) *isolating the hazard giving rise to the risk to prevent any person coming into contact with it:*

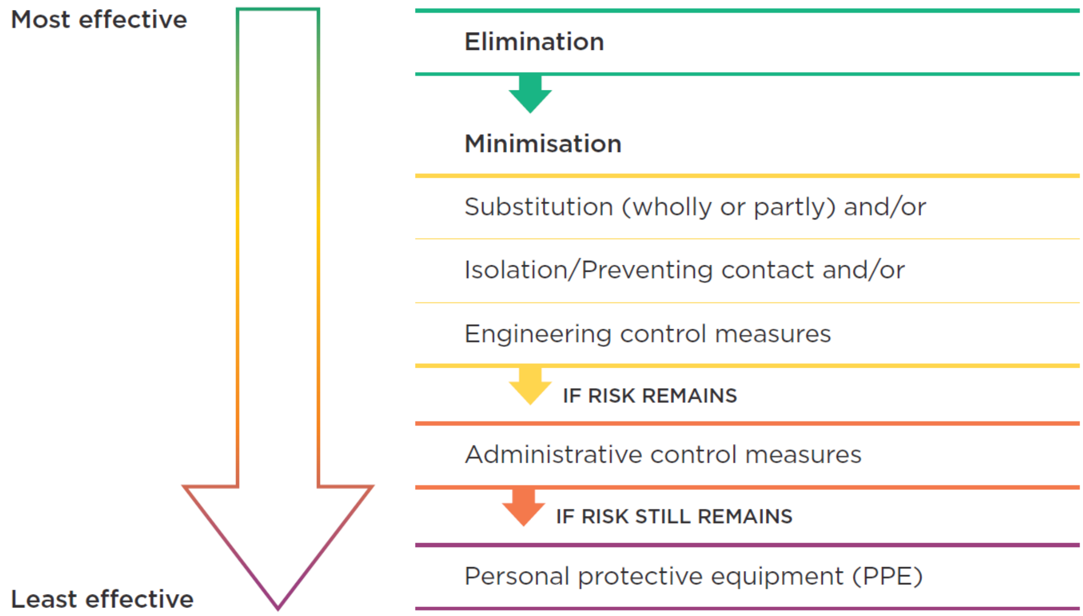
(c) *implementing engineering controls.*

(4) *If a risk then remains, the PCBU must minimise the remaining risk, so far as is reasonably practicable, by implementing administrative controls.*

(5) *If a risk then remains, the PCBU must minimise the remaining risk by ensuring the provision and use of suitable personal protective equipment.*

The WorkSafe Mahi Haumaru Aotearoa (2017) definition of hierarchy of controls references the Health and Safety at Work (General Risk and Workplace Management) Regulations. The hierarchy of controls from WorkSafe Mahi Haumaru Aotearoa (2017) has been applied in this research (Figure 1.3). The hierarchy of controls in the TTM context is described in section 2.6.2.

Figure 1.3 Hierarchy of controls (reprinted from WorkSafe Mahi Haumaru Aotearoa, 2017)



1.5.4 Near miss/Serious near miss

For the purposes of this report, near miss types are as follows:

- **Near miss:** An incident that did not result in injury, damage or other loss, but potentially could have. For example, where a worker trips over but does not suffer an injury (adapted from University of Auckland, n.d.; see section 2.8).
- **Serious near miss:** Near misses that had the potential to result in serious injury or fatality. For example, where a car or work vehicle almost hits a worker.

2 Literature review

This literature review provides background information to support evaluation of a risk-based approach to TTM in New Zealand.

The literature review firstly establishes the purpose of TTM before going on to look at TTM-related crashes in New Zealand. The review then details human elements associated with TTM and communication to drivers before looking at risks where the focus is risk reduction.

2.1 Method

A targeted literature review was conducted to review international and national published research and grey literature around solutions that help solve risk-based safety concerns at TTM sites. A snowball approach was applied, starting with the contributing authors' research collected throughout over 100 collective years of experience in this field. The literature review was supplemented with information gained through engagement with national and international industry groups via personal email communication through the researchers' contacts. The authors' experience and knowledge in this field enabled selection of appropriate grey literature to reliably inform this research. To support the literature review, an analysis of the Waka Kotahi Crash Analysis System (CAS) was performed. CAS contains details of reported crashes involving motor vehicles. Data on crashes occurring at work sites for the 16-year period 2006–2021 was investigated.

2.2 The purpose of TTM

The purpose of TTM is three-fold:

- to protect road workers from road users
- to protect road users from any hazards related to the work site
- to reduce disruption to traffic flows during the work.

This review relates primarily to the safety side of TTM. The operation of TTM in New Zealand is subject to a zero-harm approach. This derives from both the Waka Kotahi Safe System approach to road safety as part of the Vision Zero strategy to eliminate traffic-related fatalities and serious injuries, and the WorkSafe Mahi Haumaru Aotearoa vision for zero workplace harm.

This means that TTM must be set up so that both road workers and other road users are protected. These two goals are synergistic as often measures to protect one will also protect the other. This is because any collision or near miss between two parties (eg, a conflict between a vehicle and a road worker in a live lane) is potentially hazardous to both parties. A hypothetical example is when a vehicle swerves into a barrier to avoid an exposed road worker.

The European Transport Safety Council (ETSC, 2011)[2] reports that, in a 2006–2007 Netherlands study, it was found that road workers' fatality risk was significantly higher than that faced by general construction workers. Similarly, in the UK, the average death rate for road workers continues to be one of the highest for employment sectors reported by the Health and Safety Executive. A survey released by the UK Highways Agency in 2006 suggested that up to 20% of road workers had suffered some injury caused by passing

[2] ETSC is a non-governmental organisation based in Brussels that works closely with European governments and government bodies to promote transport safety over all modes.

vehicles throughout the course of their careers, and 54% had experienced a near miss with a vehicle (Highways Agency, 2006, cited in Paolo & Sar, 2012).

Other injuries related to TTM involve:

- pedestrians near TTM sites but not directly associated with the TTM
- pedestrians injured while avoiding TTM sites
- occupants of passing vehicles involved in TTM-related crashes.

Pedestrians who are not road workers can be injured owing to badly set out roadworks or may be injured where the roadworks are incidental to the injury. A New Zealand statistical analysis over 15 years of crashes (including reported non-injury crashes) is mentioned in section 2.7 of this report. In this analysis, of the 35 (40% of the total) pedestrian crashes not involving road workers where roadworks were mentioned as a factor, six incidents were identified as directly related to the roadworks. Of these, four related to pedestrians being hit while walking on the road where the roadworks were either blocking the footpath or were placed in the absence of a footpath.

2.3 TTM-related crashes in New Zealand

TTM-related crashes in New Zealand were examined as a starting point in establishing the size of the problem. Our analysis of CAS data for the 16-year period 2006–2021 (inclusive) revealed an average of 314 roadworks-related crashes (including reported non-injury crashes) per year. Figure 2.1 shows the number of roadworks-related crashes divided into three groups (groups A, B and C).

Group A (roadworks specific) is composed of crashes where the factors involved in the crash include:

- ‘Failed to notice road works signs’ (factor code 339)
- ‘Road under construction or maintenance’ (factor code 817)
- ‘Road works not adequately lit or signposted’ (factor code 824).

One caveat that requires mention is that factor 817 ‘Road under construction or maintenance’ may be over-reported as roadworks are sometimes coded by the Police when they are present, even in the absence of evidence that they contributed causatively to the crash.

Group B (struck object related to roadworks) is composed of crashes in which:

- the crash movement is ‘struck workman’s vehicle’ (movement code ‘ED’)
- the object struck is ‘roadworks’ (object code ‘R’).

Group C is composed of crashes where a crash factor cited in the crash report denotes a situation where vehicles travel ‘too fast for conditions at temporary speed limit’ (factor code 116).

Figure 2.1 illustrates how the different groups combine to provide a picture of the crashes at roadworks sites.

Figure 2.1 Reported crashes at roadworks sites, by crash group, 2006–2021 inclusive

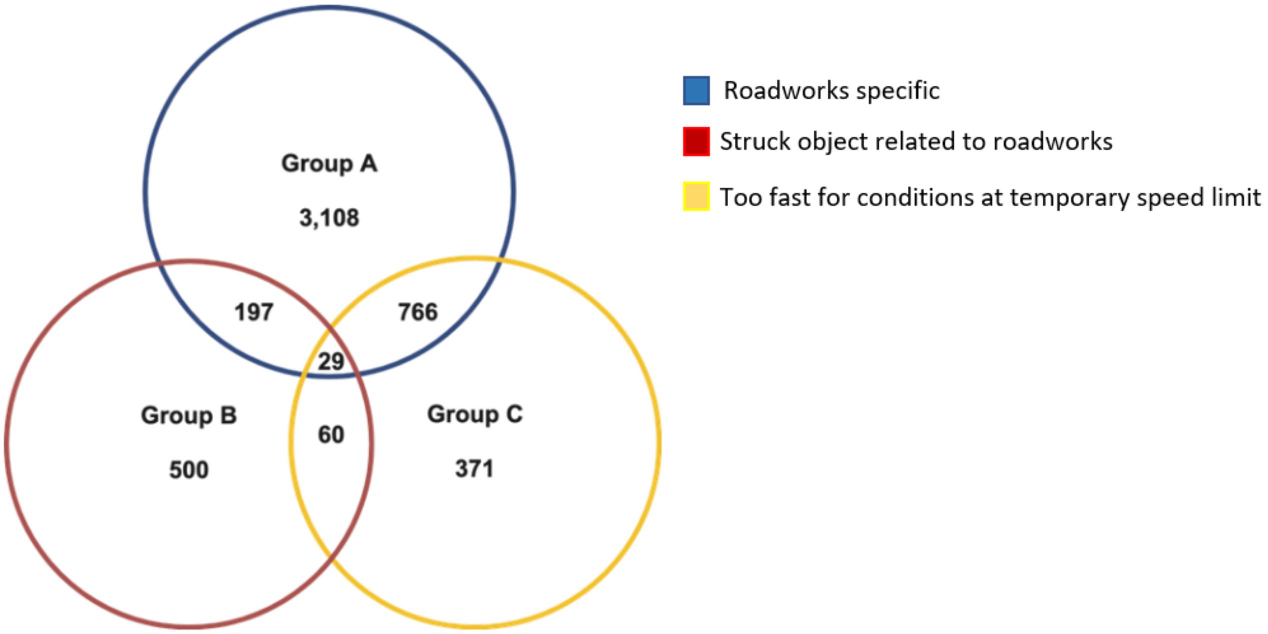


Figure 2.1 shows that, of 5,031 reported crashes (including non-injury crashes) for the period between 2006 and 2021 (inclusive), there were 371 crashes (7.3%) that may be marginal in their relation to the presence of roadworks in that they involved only travelling too fast at a temporary speed limit. Eighty-one percent are in group A.

Table 2.1 provides a breakdown of crashes by severity for each group, demonstrating the size of the problem. The proportion of non-injury crashes was highest in group B (69.7% compared with 64.7% and 60.2% in groups A and C, respectively), while the proportion of serious and fatal injuries was highest in group A (7.3%, compared with 7.1% and 6.8% in groups B and C, respectively).

Table 2.1 Breakdown by severity of the crashes in groups A, B and C

Group	Non-injury	Minor injury	Serious injury	Fatal	Total
A	2,652	1,150	253	45	**4,100**
B	548	182	47	9	**786**
C	738	405	64	19	**1,226**

2.4 The human element

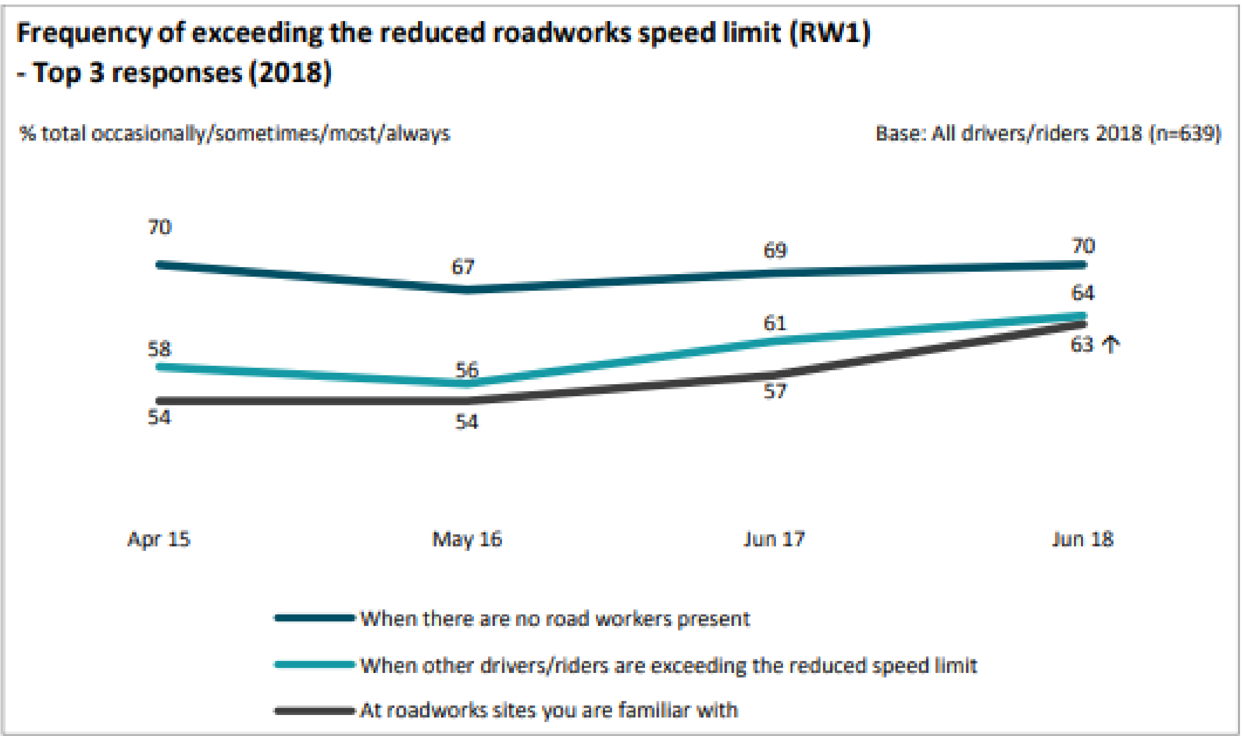
TTM involves a complex interaction between road users, road workers, and infrastructure. Therefore, human factors are very important in this context.

2.4.1 The credibility of TTM warnings (ghost TTM sites)

Drivers may take less notice of advance warning of TTM sites if they are accustomed to complying with warnings only to find the site is not operating. Jamson (2008), in an unpublished report to Highways England (as cited in Royal Society for the Prevention of Accidents, n.d.), found that focus groups reported significant frustration with roadworks where no one was apparently working. Drivers reported that they lost confidence in advanced signing, and simulator trials revealed more aggressive driving and shorter following distances by drivers who had experienced ‘ghost’[3] roadworks.

The Queensland Department of Transport and Main Roads has been aware of the credibility of roadworks signage as an ongoing issue. Consequently, they have included questions in their annual Road Safety Perceptions and Attitudes surveys on compliance with reduced speed limits at roadworks sites, including those left unattended. The responses over the years 2015 to 2018 are depicted in Figure 2.2 and indicate that around 70% of drivers interviewed stated that they exceeded the speed limit in the absence of road workers.

Figure 2.2 Frequency of exceeding a reduced roadworks speed limit under three conditions (reprinted from Queensland Department of Transport and Main Roads, 2018, p. 60)



In the United States, a distinction is made between active work zones and inactive work zones. Active work zones are those where workers are on the job. Inactive work zones are designated by traffic control devices such as signs and flashing lights at beginning and end (Figure 2.3) and may have lower speed limits enforced during periods of activity (Heneghans, 2018).

[3] Ghost roadworks are roadworks where no work is actually being undertaken.

Figure 2.3 US active work zone signs (reprinted from Gannett Fleming, 2007, p. 1)

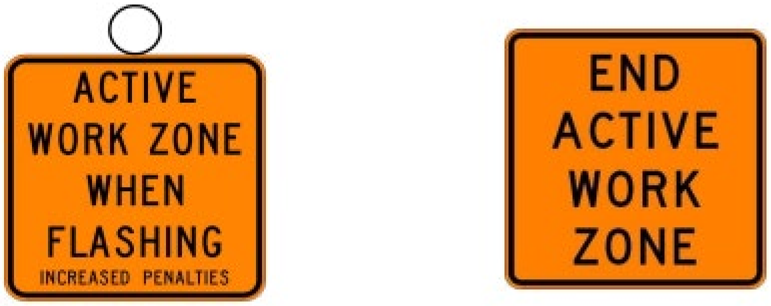


Figure 2.4 depicts a Pennsylvanian TTM sign warning of camera enforcement of a lower speed limit while TTM is active.

Figure 2.4 Pennsylvanian sign warning of camera speed enforcement during active TTM (reprinted from Boeckel, 2020, p. 6)

There appear to be no published evaluations of the impact of the differentiation between active and inactive TTM. There is a risk that if workers forget to put out the signage/lights, drivers may think the site is inactive and drive accordingly. Conversely, the signage/lights may be left out when workers are absent, thus annoying drivers by giving a false alarm.

2.4.2 Drivers

Strnad et al. (2019, p. 8) provide the following list of human factors that may impact on a driver's reaction to TTM.

- ***Attention***: *attention is the behavioural and cognitive process of selectively concentrating on specific information, while ignoring other perceivable information*
- ***Divided attention***: *in a traffic situation, attention is spread over all the various aspects that are relevant for the driving task, which leads to a divided attention*
- ***Inattention*** *is a general state of less attention or awareness*
- ***Inattentional blindness:*** *if a person is really focusing on a specific action (texting, telephone conversation, looking for a specific place) exogenous cues would not always be sufficient*

- ***Unintentional blindness:*** *causes certain events in our field of vision to go unnoticed. It is about occurrences we did not expect in a given situation and we are not focusing on. It looks as if we cannot see it because it does not match our expectations.*
- ***Cognitive workload:*** *drivers can only handle a limited amount of information at the same time, the attention capacity has limits*
- ***Useful field of view (UFOV):*** *it means the area in which we can detect and process information without moving our head and eyes; the UFOV is narrowing with increasing speed*
- ***Camouflage:*** *impaired visual function, perceptual illusions, deterioration to perceive objects in the dark*
- ***Emotions***

As a result of examining a work zone crash analysis by Ullman, Pratt et al. (2018), Varhelyi et al. (2019, p. 11) produced the following list of important human factors.

- *Physical condition of the driver (health problems, fatigue, driving under the influence of alcohol/drugs)*
- *Distraction of the driver (due to physical condition, use of devices, passengers, distraction by events outside the car)*
- *Confusion/uncertainty about the situation (which lane/direction to take, restricted overview of the situation, distance challenges)*

In a follow-up, Ullman, Fontaine et al. (2018) found that the greatest challenges to drivers associated with TTM are related to lack of space. These challenges are summarised by Varhelyi et al. (2019, p. 11) as follows.

- *Due to reduction of space and depending on the traffic density, work zones can lead to congestion; congestion is not always expected by drivers.*
- *Reduction of available space can require closing of lanes; temporary travel path changes might be necessary which can lead to confusion.*
- *Lanes are often narrower, and the work zone can be close to the lane. This reduces the possibilities to manoeuvre and makes it more difficult to recover from small mistakes.*

2.4.3 Road workers

Working on a road including live roads and work sites is by its nature risky, and Strnad et al. (2019) make several relevant points about that risk.

Road workers, after a higher risk learning phase, may have a period of lower risk after which they may become more blasé about these risks. This happens as they become more used to their environment and is called habituation. It may also be accompanied by workers over-rating their own competence, which can lead to excessive risk-taking. This is similar to the common finding (see Roy & Liersch, 2013) that most car drivers rate themselves as above average.

Another aspect is that workers, perceiving danger, may overreact to it. An example is workers over-lighting their work site, to the detriment of safety, because it makes them feel safer.

Also, workloads need to be fine-tuned so that workers do not become less safe due to the perception that they cannot follow proper safety procedures because of time pressures. Thus, contractors need to be careful not to make speed of work a utilisation measure, to the detriment of safety. Further, their clients need to be careful that their deadlines are realistic.

2.4.4 Practical rules and principles

The above human factor considerations have been codified into practical rules and principles. Strnad et al. (2019, p. 9) propose the following '*basic psychological rules*':

- *Keep the driver in mind when arranging and designing a work zone – usually possible dangers are underestimated, drivers don't realize the impact of speed on stopping distances, get confused, have difficulties in perception at night.*
- *Keep the cognitive workload low – use text messages only when necessary, use simple signs, allow enough time for perception of signage.*
- *Avoid surprises – drivers always comes back to what they know and expect.*
- *Avoid confusion – non-relevant events and misleading elements can distract the driver from the driving task and influence the interpretation of the situation, leading to accidents.*

The World Road Association (PIARC, 2012, as cited in Strnad et al., 2019, pp. 9–10) proposed the following principles for the 'safe, efficient and effective management of road work zones':

- *Conspicuous – this implies that the driver must be physically able to see what is coming up. The work zone must be obvious, noticeable and eye-catching to draw the attention of the drivers and encourage them to act in the desired way with regard to increased attention, speed adaptation and position of vehicle.*
- *Clear means that all signing, guiding and other instructions through road works must be clear for drivers so they can be certain about what is required in terms of correct decisions about how to safely approach and pass the site.*
- *Consistent implies that drivers should encounter uniform standards, layouts and arrangements at all work zone sites of the same kind, so they are conditioned to act in a certain expected way.*
- *Credible means that the instructions are 'believable' so the drivers can rely on what they are told (e.g. the need to slow down) and that the messages they are given are a true representation of what will occur ahead.*

2.4.5 Summary takeaways

TTM involves a complex interaction between road users, road workers, and infrastructure. Therefore, human factors are very important in this context. To summarise:

- Working on a road is by its nature risky. Workers may become complacent and over-rate their own competence.
- Warnings of TTM should be credible. Drivers may take less notice of advance warning of TTM sites if they are accustomed to complying with warnings only to find the site is not operating.
- There are many human factors that interact to influence how a driver reacts to a TTM site. These relate to the driver's physical condition, distraction, and confusion/uncertainty about the situation. Drivers find lack of space very challenging.
- Workers perceiving danger may overreact to it.

- Workloads need to be fine-tuned so that workers do not become less safe due to perceiving that they are in too much of a hurry to follow proper safety procedures.

The points above distil down to the following practical rules and principles for TTM sites.

Rules

- Keep the driver in mind.
- Keep the cognitive workload low.
- Avoid surprises.
- Avoid confusion.

Principles

The site should be:

- conspicuous
- clear
- consistent
- credible.

2.5 Communicating to drivers: Warning and visibility of site

Workers' and vehicle occupants' exposure to risk is reduced if all aspects of the site (ie, relevant to the drivers' behaviour as they approach the site) are effectively communicated to drivers. This means that the following need to be at the forefront of Safe System best practice:

- signage quality
- lighting quality
- speed limit appropriateness, including conformance with Safe System speed limit principles
- quality of the physical approaches in terms of road safety engineering, driver psychology and Safe System best practice.

To quote Brewer et al. (2014):

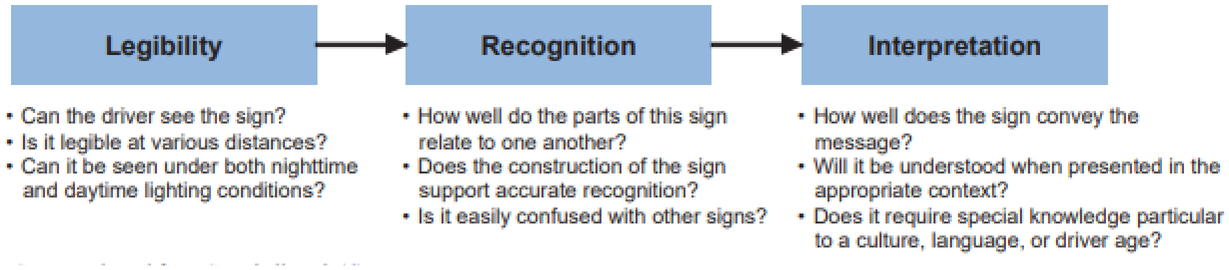
> *Work-zone traffic control must provide adequate notice to motorists that describes the condition ahead, the location, and the required driver response. Once drivers reach a work zone, pavement markings, signing, and channelization must be conspicuous and unambiguous in providing guidance through the area.* (p. 77)

2.5.1 Signage

2.5.1.1 General comments

It is important that road users have excellent warning when approaching TTM sites so they can make all necessary changes to their speed and direction of driving in plenty of time. This means that signage needs to have excellent clarity of meaning at adequate preview distances. The diagram in Figure 2.5 describes the sequence of stages associated with comprehension and use of signs.

Figure 2.5 The three stages associated with comprehension and use of signs (reprinted from Campbell et al., 2012, p. 18-9)



All signage approaching TTM sites should be able to stand up to the scrutiny implied by Campbell et al. (2012). This includes both the signage's daytime and night-time characteristics.

The following general comments apply.

- For all age groups symbolic signs are better than text-based signs. Some symbolic signs are better than others, with simplicity the key. So, they should be designed with care.

  The literature's consensus is that, where possible, symbols should be used rather than words. For example, Kline et al. (1990) compared the visibility distances for young, middle-aged and older observers of text and symbolic versions of four different highway signs under day and dusk conditions. They found no age-related differences, but the symbolic signs had much greater visibility distances than the text signs for all age groups, with the difference being more pronounced at dusk. No age differences were detected in the comprehension of symbolic signs, but different signs differed in their comprehensibility. Overall, symbolic signs appeared to offer all drivers almost twice as much time to respond than text signs.

- The Highway Gothic fonts used in New Zealand traffic signs appear to be fit for purpose.

  New Zealand traffic sign fonts are based on Highway Gothic, a font developed in the 1940s by the US Federal Highway Administration designed to be easily read at speed on highways. After much research there have been no strong moves to change to any other font.

- Font size should be as large as possible given the circumstances of the sign to give the driver as much preview time as possible.

The Austroads (2021a) *Guide to Temporary Traffic Management* recommends that:

> *At locations where the background and surroundings to the sign have a large amount of material that would make the sign difficult to see (e.g., urban areas with illuminated advertising signs, shop fronts or other lights), a larger legend and sign may be used at the discretion of the designer.* (p. 37)

The above criteria could well apply at TTM sites, and where it does, the associated advice should be used.

2.5.2 Lighting

The literature on TTM lighting is relatively sparse given that a significant amount of TTM is carried out at night to avoid large traffic flows. Transport for New South Wales (2022) states that at night:

> - *Obstacles are less conspicuous and peripheral vision is reduced; and*
> - *There is a higher risk of motorists being fatigued, alcohol-impaired or driving at higher speeds.* (p. 85)

This is followed up in Table 5-10 of Transport for New South Wales (2022), which says:

> *PTCDs* [portable traffic control devices] *or traffic controllers with STOP/SLOW bats at the approaches to a night time work area must be clearly visible to road users. This may require additional lighting.*
>
> *The ITCP [implement traffic control plan], works supervisor or team leader must check floodlighting at work sites to ensure that floodlights do not adversely affect road users, adjacent dwellings or businesses. These checks must be made by driving around, past and through the work site in all directions of travel. On divided carriageway roads, these checks must be carried out from all carriageways, even if the work area is only on one carriageway.* (p. 85)

Glare is described by Triaster (1982, cited in Odeh, 2010) as:

> *a term used to describe the sensation of annoyance, discomfort or loss of visual performance and visibility produced by experiencing luminance in the visual field significantly greater than that to which eyes of the observer are adapted.* (p. 4)

Disability glare directly reduces visual performance, while discomfort glare causes the motorist to feel less comfortable and may distract a driver's attention from the road to the glare source (van Bommel, 2014). The lighting must be such that approaching motorists are not distracted by glare, and such that workers who may also be subject to glare can carry out their tasks safely and effectively. It is also hard for drivers to adjust to extreme changes in lighting levels when moving from a relatively dark roadway environment to a relatively brightly lit work zone. Similarly, workers' vision may suffer from overly bright lighting, impaired by bright and direct lighting sources.

Figure 2.6 illustrates blinding glare from sub-optimal illumination at a US freeway work zone.

Figure 2.6 Blinding glare approaching a US freeway work zone caused by sub-optimal illumination (reprinted from Anani, 2015, p. 3)

a. Approximately ½ mile upstream of luminaire.

b. Approaching luminaire.

To avoid problems, Anani (2015, p. 3) suggests that in the US context:

- *Minimum and maximum illumination levels should be specified in the contractual documents, along with preferred illumination methods.*
- *The contractual documents should include provisions for agency approval of the type and location of contractor-supplied lighting. Typically, this can be accomplished either by means*

of shop drawings or through a field demonstration at least 24 hours prior to the start of each new lighting set-up.

- *Contractual provisions should be established to require the contractor to modify the lighting system if it presents a safety hazard to workers, drivers, or other road users.*

According to Odeh (2010, p. 27) several factors impact on glare levels around night TTM sites. These include:

(1) type and intensity of the utilized lighting equipment;

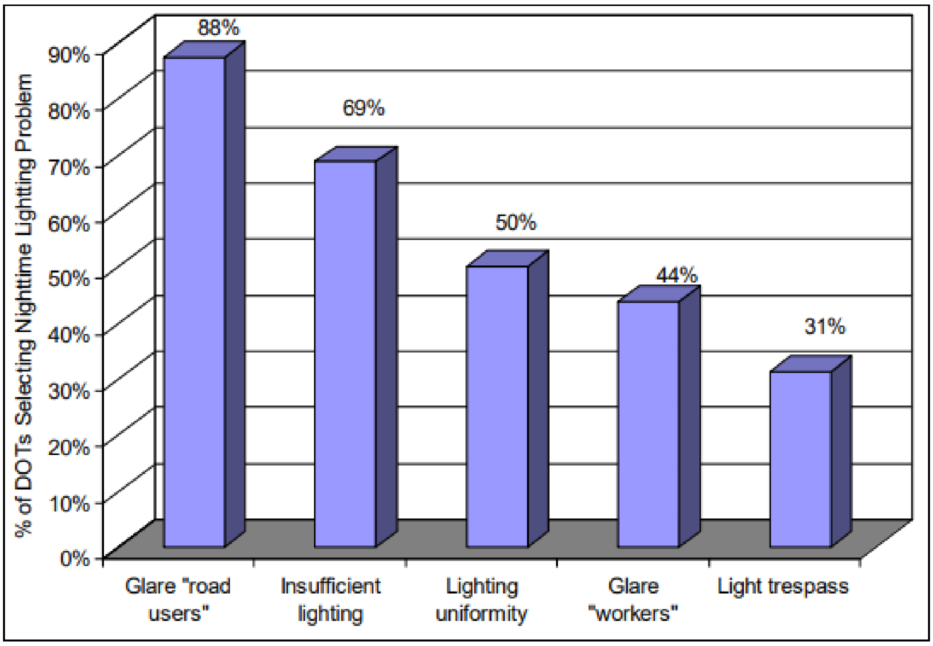
(2) location of the nighttime lights in the nighttime work zone and their proximity to drivers and construction personnel;

(3) aiming angle of the luminaries; and

(4) height of the light sources on site.

Oheh (2010) also reports results from El-Rayes et al. (2003), who conducted surveys of officials in several US state departments of transport (DOTs) about their impressions of night-time lighting problems. Glare for road users was mentioned by 88% of officials, and glare for road workers was mentioned by 44% (Figure 2.7).

Figure 2.7 Impressions of lighting problems of DOT officials in several US states (reprinted from El-Rayes et al., 2003, p. 53).



2.5.3 Summary takeaways

- **Signage quality:** Signage needs to have excellent clarity of meaning at adequate preview distances. For all age groups symbolic signs are better than text-based signs. Simplicity is the key. Font size should be as large as possible given the circumstances of the sign to give the driver as much preview time as possible.
- **Lighting quality:** Lighting must be such that all traffic controllers are clearly visible to drivers and road workers can carry out their tasks safely. Glare needs to be minimised for the benefit of both road workers

and motorists. These requirements should be specified in contract documents, which should be flexible enough to allow changes if safety needs require them.

- **Physical approaches:** These should be high quality in terms of road safety engineering and driver psychology and follow Safe System best practice.

2.6 Risk and its reduction

2.6.1 Introduction

Fowler et al. (2011, p. 27) define risk as ‘the probability or exposure to a hazard, combined with the consequences of such exposure’.

Risk matrices are widely used but suffer from severe problems of design and application (Fowler et al., 2011). Risk matrices combine the likelihood of an event occurring with the severity of the consequences to calculate a risk level. This risk level can then be used to determine whether the level of risk is tolerable. In New Zealand, risk matrices are applied in various contexts (eg, the Threat and Opportunity Risk Matrix; see New Zealand Transport Agency, 2018); however, these are not specific to TTM. Table 2.2 shows a risk matrix that was used by the British Highways Agency.

Table 2.2 British Highways Agency risk matrix (reprinted from Fowler et al., 2011, p. 28)

	5 X 5 Matrix	**IMPACT**				
		Negligible Minor injury involving no absence from work. (e.g minor cut requiring no treatment other than a plaster	**Minor** Lost time incident with absence under 3 days. (e.g slip trip or fall or something requiring visit to Doctor and/or a medical treatment	**Major** RIDDOR defined major injury/disease or defined major incident	**Very Serious** Permanent disability such as loss of limb., or indefinite inability to return to work	**Fatality (ies)** Fatality or multiple injury
		Minimal injury requiring no/minimal intervention or treatment Incident resulting in a bruise/graze No time off work	Minor injury or illness, requiring minor intervention but does not require a hospital visit Requiring time off work for <3 days Laceration, sprain, anxiety requiring occupational health counselling (but no time off work required)	Requiring time off work for over 3 days Physical attack causing injury RIDDOR/agency reportable incident	Long-term incapacity or disability such as loss of limbs, perm loss of sight. Indefinite inability to return to work	Incident leading to multiple injuries, permanent incapacity or severe disability, death or irreversible health effects
LIKLIHOOD	**Frequent** An event that is expected to occur and be experienced by most staff (100s) each year.					
	Probable An event that is expected to occur and be experienced by many staff (10s) each year					
	Occasional An event that could occur at some time and may effect several people at least once a year					
	Remote Unlikely although may affect 1 or 2 staff from the whole staff population once per year					
	Improbable So unlikely that it may never happen					

Residual Risk Rating	**Management / Employee Action**
Green	Ensure that all safe working practices in the risk assessment are adhered to.
Amber	Ensure that all safe working practices in the risk assessment are adhered to and that there are no additional Safety control measures that are reasonably practicable.
Red	This activity must not be undertaken without discussing it with your line manager and Director and getting express permission to do so.
Red Hatched	This activity must not be undertaken under any circumstances.

Table 2.3 shows a list of risk likelihood descriptions from Austroads (2021a).

Table 2.3 Risk likelihood descriptions (reprinted from Austroads, 2021a, p. 12)

Likelihood	Description
Almost certain	• Expected to occur in most circumstances or • Expected to occur at least 8 in 10 times the event or action occurs, i.e. more than a 80% chance of occurrence or • Will probably occur with a frequency in excess of 10 times per year.
Likely	• Expected to occur multiple times during any given year or • Expected to occur between 8 in 10 and 1 in 10 times the event or action occurs, i.e. between a 10% to 80% chance of occurrence or • This risk is known to occur often but less than 10 times per year
Possible	• Expected to occur once during any given year or • Expected to occur between 1 in 10 and 1 in 100 times the event or action occurs, i.e. 1% to 10% chance of occurrence or • This risk is known to have occurred on occasions
Unlikely	• Expected to occur once every 1 to10 years or • Expected to occur between 1 in 100 and 1 in 1000 times the event or action occurs, i.e. 0.1% to 1.0% chance of occurrence or • This risk could occur but not often
Rare	• Not expected to occur in the next 10 years ie less than once every 10 years or • Expected to occur less than 1 in 1000 times the event or action occurs, i.e. less than 0.1% chance of occurrence or • It is unusual that this risk occurs, but it has happened

There are assumptions used in assessing the risk likelihoods for a particular site. The main drawback of such risk matrices is that they are event based and thus do not account for time on the job, number of workers, and related exposure to risk. This is dealt with by wherever possible removing or reducing the need for workers to be placed in risky situations over time. The risk matrix also is not concerned with the nature of the risk mitigations used when setting up the site. Also, one Australian professional in the area (Dan Sullivan, personal communication, 21 December 2022) has stated that it is important to recognise that recent experience in Australia is that the selection of a mitigating measure in a risk assessment is rarely supported by any documented assessment of the hierarchy of controls. Typically, a single risk mitigation is selected, which may be administrative only without an indication that elimination has been considered first. Additionally, there seems to regularly be no consideration of the risks that the mitigation measure introduces. For example, a detour that eliminates the risk at the roadworks site can introduce new risks on the detour route.

2.6.2 TTM work site risk management

Major risks for TTM workers occur from vehicles when the worker is unprotected on a live carriageway, or when a vehicle veers off course and penetrates the protections afforded to the workers. Therefore, risk reduction TTM strategies are aimed at:

- eliminating the need for workers to be on site as much as possible
- reducing as much as possible workers' exposure to risk when on site
- reducing risk further by minimising the numbers of workers required on site
- protecting workers as much as possible when they are on site.

The Safe System approach to road safety predicates the use of risk-based approaches, and this is true for TTM as much as for any other road-related activity. Risks at TTM sites must be controlled.

Table 2.4 shows a TTM site risk rating matrix from Austroads (2021a). The risk rating determines the level of planning and protection required for the site. Austroads emphasises that it should be noted that selecting site risk for planning of TTM simply represents a starting point for the protection of workers from traffic. The overall risk rating should also include consideration of pedestrian, cyclist, and other road user risks. These factors may vary the risk rating.

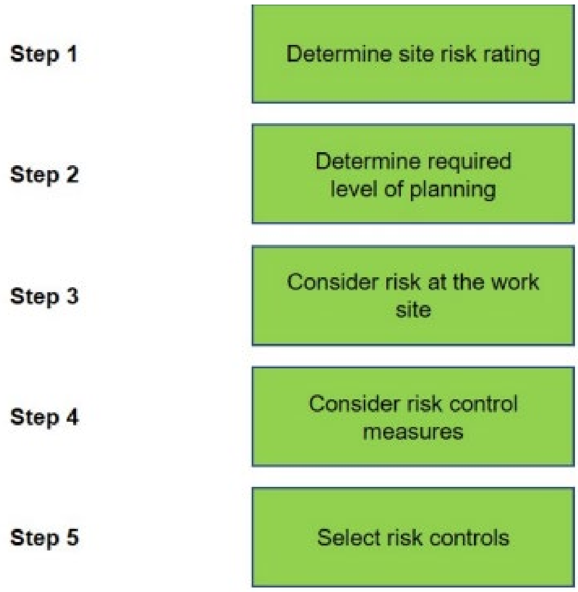
Table 2.4 Austroads risk rating matrix[4] (reprinted from Austroads, 2021a, p. 9)

Site risk rating						
		Clearance between traffic lane and workers				
		< 1.2 m	1.2 – 3.0 m	3.0 – 6.0 m	6.0 – 9.0 m	> 9.0 m
Posted speed limit and road type	40 km/h					
	Category 1 road	Medium	Low	Low	Low	Low
	Category 2 road	Medium	Low	Low	Low	Low
	50 km/h					
	Category 1 road	Medium	Low	Low	Low	Low
	Category 2 road (urban)	High	Medium	Low	Low	Low
	60 km/h or 70 km/h					
	Category 1 road	High	Medium	Low	Low	Low
	Category 2 road	High	High	Medium	Low	Low
	80 km/h or 90 km/h					
	Category 1 road	High	High	Medium	Low	Low
	Category 2 road	High	High	High	Medium	Low
	Category 3 road	High	High	High	Medium	Low
	100 km/h or higher					
	Category 1 road	High	High	High	Medium	Low
	Category 2 road	High	High	High	Medium	Low
	Category 3 road	High	High	High	Medium	Low

Austroads' (2021a) provides a summary of the steps involved in TTM work site risk management, as shown in Figure 2.8.

[4] Road categories are determined by annual average daily traffic (AADT) and speed limit.

Figure 2.8 Steps involved in TTM work site risk management (reprinted from Austroads, 2021a, p. 8)



Austroads (2021a) describes a hierarchy of controls approach, illustrated in Figure 2.9. This should be used in implementing steps 3, 4 and 5 in Figure 2.8. Control measures are grouped into six categories according to ability to control the hazard and reduce risk.

The Austroads hierarchy of controls aligns with the hierarchy of control measures in the Health and Safety at Work (General Risk and Workplace Management) Regulations and the WorkSafe Mahi Haumaru Aotearoa (2017) hierarchy of controls presented in section 1.5.

Figure 2.9 Austroads' hierarchy of controls (reprinted from Austroads, 2021a, p. 15)

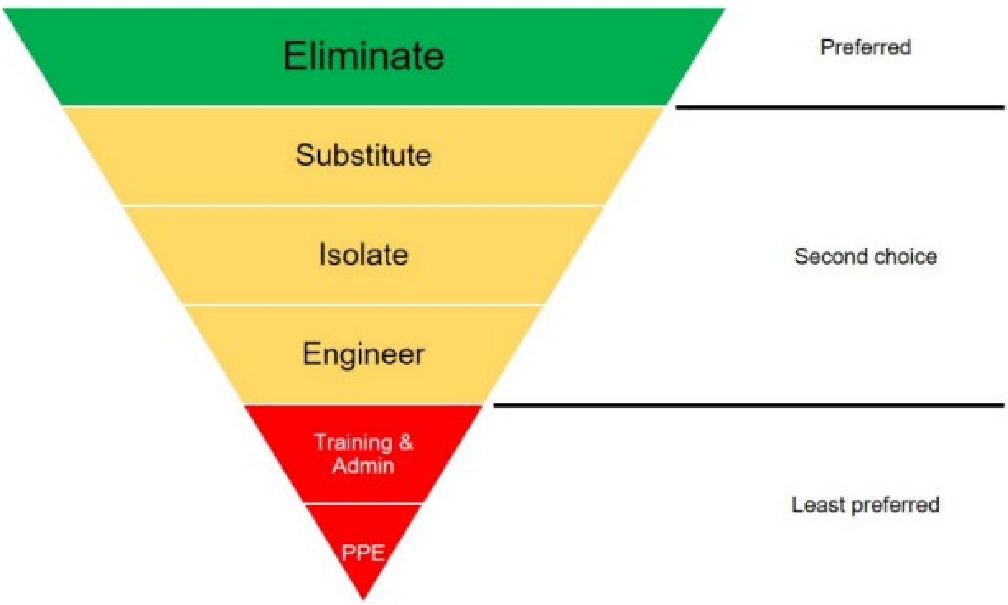


Table 2.5 describes the six categories in Figure 2.9.

Table 2.5 Descriptions of Figure 2.9 categories and mitigation examples (reprinted from Austroads, 2021a, p. 16)

Control	Description	TTM Control Example
Eliminate	The most effective control measure involves eliminating the hazard and associated risk. The best way to do this is by, firstly, not introducing the hazard into the workplace. Eliminating hazards is often cheaper and more practical to achieve at the design or planning stage of a product, process or place used for work. In these early phases, there is greater scope to design out hazards or incorporate risk control measures that are compatible with the original design and functional requirements. It may not be reasonably practicable to eliminate a hazard if doing so means that you cannot make the end product or deliver the service. If you cannot eliminate the hazard, then you must minimise as many of the risks associated with the hazard as reasonably practicable.	Redirecting traffic "Around the work area" to eliminate the risk of traffic impact on workers or implementation of contraflow to eliminate the risk of traffic impact on traffic controllers.
Substitute	Substitute the hazard with something safer. This may not remove all the hazards associated with the process or activity and can introduce different hazards, but the overall harm or health effects will be lessened.	Portable traffic control devices to substitute the requirement of a traffic controller working in or near traffic.
Isolate	Isolate the hazard by physically separating the source of harm from people by distance or barriers. For example, restrict contact with plant and equipment, lock hazardous chemicals away and only use them under strict controls	Undertaken by the use of "Through the worksite" and "Past the worksite" arrangements and appropriately rated safety barriers.
Engineer	Look for technological solutions that reduce risk, eg use machines to do work that would be hazardous to humans, or use more modern plant with in-built safety features	Truck mounted attenuators to protect workers in place of a typical work vehicle.
Training and Admin	Develop and document safe methods of work e.g. safe work procedures or safe work method statements and provide appropriate training, instruction and information to reduce the potential for harm	Developing safe methods of work e.g. safe work method statements, providing appropriate training and instructions and police enforcement etc.
Personal Protective Equipment (PPE)	Personal protective equipment (PPE) reduces workers' exposure to the hazard. PPE includes safety gloves, protective eyewear, earmuffs, hard hats, aprons, safety footwear and dust masks. PPE is the last line of defence and must be used in conjunction with one or more of the other control measures.	Hi Vis equipment and clothing, hard hat and safety boots etc.

Table 2.6 looks at common TTM control measures and relates them to the hierarchy of controls. The control measures in the right-most column are preferred, with lesser measures used only if the higher levels of control are judged impractical.

Table 2.6 Common work site risks and TTM control measures related to the hierarchy of controls (reprinted from Austroads, 2021a, p. 17)

Safety hazard/risk factors	Hierarchy of control		
	Consider the practicability of controls, from left to right. Select the most practical given the circumstances and the level of risk. Record the reason if a higher-level control is not considered practicable.		
	Elimination/substitution	Engineering/isolation	Administrative/behavioural
Clearance to traffic (between the lane carrying traffic and the work area)	Road closure Detour Side-track	Safety barriers Lane closure Vehicle crash attenuators	Speed restriction Warning signs/VMS Delineation of travel path
High speed traffic through the worksite	Road closure Detour Side-track	Safety barriers Lane closure Portable traffic signals Vehicle crash attenuators	Speed restriction Warning signs/VMS Traffic controller
Poor advance sight distance to the worksite (<200 metres)	Road closure Traffic diversion	Safety barriers Lead and/or tail vehicles	Extra advanced warning signs/VMS Speed reduction Delineation of the travel path Traffic controller
Poor observance by motorists of directions/instructions	Road closure Traffic diversion	Lane closure Portable traffic signals	Speed reduction Police presence on site Extra signs/VMS Reassessment of information provided
Narrow pavement width with no escape route (< 2.9 metres width)	Road closure Traffic diversion	Safety barriers	Speed reduction Delineation of travel path
Presence of workers at the worksite	Road closure Traffic diversion	Safety barriers Increase separation from vehicular traffic	Speed reduction Warning signs Delineation of travel path and worksite
Excavation adjacent to traffic (>300 mm deep within 1.2 m of traffic)	Road closure Traffic diversion	Different construction method Safety barriers	Speed reduction Delineation of travel path
Presence of unprotected hazards within clear zone	Road closure Traffic diversion	Safety barriers	Speed reduction Delineation of travel path
Rough or unsealed road surface due to roadworks	Road closure Traffic diversion		Speed reduction Warning signs/VMS
High volume of traffic through the worksite (>10 000 vehicles per day)	Road closure Detour Side track	Safety barriers Lane closure Portable traffic signals	Speed reduction
High volume of heavy vehicles through the worksite	Road closure Detour Side track	Safety barriers Lane closure Portable traffic signals	Speed reduction
Works vehicles entering/leaving the worksite		Safety barriers Lane closure Portable traffic signals	Speed reduction Warning signs/VMS Delineation/control of access points
Cyclists/pedestrians through the worksite	Alternate pathway Close traffic lane for use by cyclists / pedestrians Eliminate impacts on pedestrians/cyclists	Adequate separation of shared road space	Speed reduction Warning signs/VMS Delineation from other traffic

2.6.3 Operationalising risk control

TTM providers and regulators operationalise steps 4 (consider risk control measures) and 5 (select risk controls) from Figure 2.8 in different ways, with different acronyms, but with the same aim in view. Two approaches applied internationally are detailed in this section.

2.6.3.1 The British Columbian approach

The British Columbia Ministry of Transportation and Infrastructure (2020) uses a structured process to classify projects:

1. **Initial Project Category Assessment** to assess the roadway and traffic features.
2. **Project Risk Analysis** to identify the project-specific risks.
3. **Final Product Category Determination** combines the initial project category assessment with the project risk analysis to determine the final project category.

The final category definitions are:

> *Category 1 – minimal impact on the travelling public, are typically located on simple terrain, and involve two-lane highways or roads, often with lower speeds and traffic volumes.*
>
> *Category 2 – may be located on higher-speed or higher-volume corridors and involve some complexity. Impacts on the travelling public may be moderate because of the roadway characteristics or the type of work.*
>
> *Category 3 – complex and have a significant impact on the travelling public because of factors such as higher volumes and speeds, project duration, active night work, mountainous terrain, and/or a requirement for lane closures and/or detours*. (p. 3-4).

The initial project category assessment is carried out using a points system utilising the table shown in Table 2.7.

Table 2.7 Initial project category assessment (reprinted from British Columbia Ministry of Transportation and Infrastructure, 2020, pp. 3-5 to 3-7)

Traffic Consideration	Value	Point Value	Score
Posted or Statutory Speed Regular posted speed limit of the roadway	≤ 50 km/hr	1 point	
	60 - 70 km/hr	3 points	
	≥ 80 km/hr	4 points	
Traffic Volume Traffic volume (both directions) in peak hours	< 1,000 vehicles/hr	1 point	
	1,000 to 3,000 vehicles/hr	3 points	
	> 3,000 vehicles/hr	4 points	
Lanes Number of lanes in both directions (including auxiliary lanes)	2 lanes	0 point	
	3 lanes	2 points	
	4 lanes or more	3 points	
Encroachment Location of work	Off roadway	0 point	
	Shoulder work/partial lane closure	3 points	
	Full lane closure, ramp closure, or intersection closure	4 points	
Detours	No detour during construction	0 point	
	Detour traffic on temporary roadway during construction next to work zone.	3 points	
	Detour route during construction takes traffic off regular route away from work zone; requires detour signing	4 points	
Duration of Work	Short-duration work (no more than one day-time shift).	1 point	
	Long-duration work (less than 2 weeks)	2 points	
	Long-duration work (2 or more weeks)	4 points	
Allowable Delays Delay time plus time to travel through work zone in minutes	< 20 minutes	1 point	
	≥ 20 minutes	3 points	
	No allowable delay	4 points	
Time of Day Time of day that work will occur	Day-time only work	1 point	
	Active day-time work, with traffic control devices in place at night	3 points	
	Active night-time work	4 points	
Vertical Alignment	Flat terrain	0 point	
	Rolling terrain	1 point	
	Mountainous terrain	2 points	
Horizontal Alignment	Tangent	0 point	
	Horizontal curves, no curve advisory speeds	1 point	
	Horizontal curves, with curve advisory speeds	2 points	
Intersections	No intersections or stop-controlled intersection(s)	0 point	
	Signalized intersection(s) with no left or right turn phases, or single lane roundabout	2 points	
	Signalized intersection(s) with left or right turn phase(s), or multi-lane roundabout	4 points	
	Interchange(s)	5 points	
Runaway Lanes	No runaway lanes	0 point	
	Runaway lanes in or near the work zone; they will not be blocked at any time during course of work	1 point	
	Runaway lanes in or near work zone; they may be blocked by work or queues during course of work	4 points	
Pedestrians and Cyclists	No pedestrians or cyclists	0 point	
	Possible pedestrians and cyclists	2 points	
	Designated cycle route, sidewalk or multi-use pathway	3 points	
HOV or Bus Lane	No HOV or bus lane	0 point	
	HOV or bus lane	4 points	
Counter-Flow Lane	No counter-flow lane	0 point	
	Counter-flow lane	4 points	
		Total Score	
		Category 1	< 16
		Category 2	16 to 25
		Category 3	> 25
		Initial Project Category	

The points scored at the end of Table 2.7 determine whether the project is assessed as category 1, 2 or 3. It is notable that some of the traffic considerations in Table 2.7 relate to exposure to risk, indicating that exposure to risk is dealt with indirectly as part of determining the project category rather than in the risk analysis.

A risk analysis is then carried out, as illustrated in Table 2.8. The points scored at the end of Table 2.8 determine if the project is considered low, medium or high risk.

Table 2.8 Project risk analysis (reprinted from British Columbia Ministry of Transportation and Infrastructure, 2020, pp. 3-8 to 3-10)

Item	Risk	Definition	Point Value	Score
Falling object	Low	Potential of falling object through course of work (i.e., overhead works, slung loads, or equipment boom/bucket work)	1 point	
	Medium	Working within a known avalanche or rock fall area; no recent evidence of activity	2 points	
	High	Recent evidence of rock or material entering work site or overhead work that may impact travelling public or worker safety (i.e., overhead structures) Vehicle queues may back into a rock fall or avalanche area	3 points	
Nature of work activity	Low	Work activity is not expected to create a significant hazard	1 point	
	Medium	Work activity will create excessive dirt, dust, or gravel on the road surface, and will thereby create a potential hazard	2 points	
	High	Work activity such as blasting, scaling, or excavation < 2 metres from active travelling lanes will create a potential hazard	3 points	
Removal of safety devices	Low	No removal of safety devices	1 point	
	Medium	Removal of safety devices such as pavement markings, signage, traffic signal, or reflectors	2 points	
	High	Removal of containment devices, such as barrier, guard rail, crash attenuators, fencing, etc.	3 points	
Equipment movement through work zone	Low	Minimal conflict with traffic (e.g., work commencing off travelled roadway)	1 point	
	Medium	Conflict with normal traffic flow; no queuing or traffic stoppages	2 points	
	High	Conflicts with normal traffic; may create queuing and require traffic stoppages. Difficult for equipment to enter and exit site	3 points	
Roadway surface condition during construction	Low	Roadway surface is maintained	1 point	
	Medium	Roadway surface, such as milling and grinding (consistent surface), creates a hazard for road users	2 points	
	High	Roadway surface is inconsistent, with multiple changes or work tasks (manholes, culvert installation, etc.)	3 points	
Storage of equipment and material	Low	Stored outside the shoulder	1 point	
	Medium	Stored on the shoulder but outside travelled roadway	2 points	
	High	Stored on shoulder but encroaching on travelled roadway	3 points	
Load restrictions as a result of construction	Low	No load restrictions	1 point	
	Medium	Narrow lanes restrict wide loads	2 points	
	High	Overweight/overheight vehicles restricted (may result in structural damage)	3 points	
Lane widths	Low	Maintain existing lane widths	1 point	
	Medium	n/a	n/a	
	High	Lane width not maintained throughout work zone, or Single-lane alternating traffic	3 points	
Work zone or queues block access (active or inactive site)	Low	None	1 point	
	Medium	Side street or business access	2 points	
	High	Major public facility and/or major secondary roadway	3 points	
Transit access	Low	No transit or school bus stops	1 point	
	Medium	Community shuttle or school bus stops	2 points	
	High	Express transit or major bus route	3 points	
Impacts of special events	Low	No known event	1 point	
	Medium	Moderate public event with attendance under 5,000	2 points	
	High	Major public event with attendance over 5,000 or moderate public event (under 5,000) with no alternative access or route	3 points	
Overlapping work	Low	No overlapping work	1 point	
	Medium	Another work site within 3 km; traffic control for the projects could impact one another	2 points	
	High	Work sites adjacent or overlapping	3 points	
Emergency facility (ie. hospital, police, ambulance, and fire stations)	Low	No emergency facility near work site	1 point	
	Medium	24-hour manned emergency facility	2 points	
	High	Volunteer-staffed emergency facility; consider responder access through work zone to the facility, and emergency response from facility through the work zone	3 points	
			Total Score	
			Low Risk	< 23
			Medium Risk	23 to 28
			High Risk	> 28
			Project Risk	

The project's initial category and risk analysis results are then combined to decide the final project category based on roadway and traffic characteristics and risks. The roadway and traffic characteristics relate to risk, although not specifically identified in that way. The two scores are combined using the risk matrix in Table 2.9.

The final category determines what needs to be addressed in the traffic management plan and other possible sub-plans, including a traffic control plan, an incident management plan, an implementation plan for incident management, and a public information plan (for closures of more than 10 min).

Table 2.9 Final project category determination matrix (reprinted from British Columbia Ministry of Transportation and Infrastructure, 2020, p. 3-11)

		Initial Project Category Assessment		
		1	2	3
Project Risk	Low	Category 1	Category 2	Category 3
	Medium	Category 1	Category 2	Category 3
	High	Category 2	Category 3	Category 3

2.6.3.2 The Western Australian approach

Western Australia uses a qualitative process to come up with a residual risk rating after controlling or reducing identified risks 'so far as practical' in accordance with the Austroads hierarchy of controls (see Figure 2.9). If the residual risk rating is very high, then it is unacceptable. The process is undertaken in accordance with AS/NZS ISO 31000 (see Standards New Zealand, 2009), and the likelihood and consequences are rated and the controls are determined using Tables 2.10 to 2.12 below.

Table 2.10 is used to rate the impact of the work on the network, and Table 2.11 is used to rate the impact on injury.

Table 2.10 Occupational safety and health qualitative measures of network impact (Main Roads Western Australia, 2022, p. iv)

Consequence	Description
Insignificant	Midblock hourly traffic flow per lane is equal to or less than the allowable lane capacity detailed in AGTTM. No impact to the performance of the network. Affected intersection leg operates at a Level of Service (LoS) of A or B. No property damage.
Minor	Midblock hourly traffic flow per lane is greater than the allowable road capacity and less than 110% of the allowable road capacity as detailed in AGTTM. Minor impact to the performance of the network. Intersection performance operates at a Level of Service (LoS) of C. Minor property damage.
Moderate	Midblock hourly traffic flow per lane is equal to and greater than 110% and less than 135% of allowable road capacity as detailed in AGTTM. Moderate impact to the performance of the network. Intersection performance operates at a Level of Service (LoS) of D. Moderate property damage.
Major	Midblock hourly traffic flow per lane is equal to and greater than 135% and less then170% of allowable road capacity as detailed in AGTTM. Major impact to the performance of the network. Intersection performance operates at a Level of Service (LoS) of E. Major property damage.
Catastrophic	Midblock hourly traffic flow per lane is equal to and greater than 170% of allowable road capacity as detailed in AGTTM. Unacceptable impact to the performance of the network. Intersection performance operates at a Level of Service (LoS) of F. Total property damage.

Table 2.11 Occupational safety and health qualitative measures of injury impact (Main Roads Western Australia, 2022, p. v)

Level	Consequence	Description
1	Insignificant	No treatment required
2	Minor	First aid treatment required.
3	Moderate	Medical treatment required or Lost Time Injury
4	Major	Single fatality or major injuries or severe permanent disablement
5	Catastrophic	Multiple fatalities.

Table 2.12 Qualitative measures of likelihood (Main Roads Western Australia, 2022, p. v)

Likelihood	Description
Rare	The event or hazard: may occur only in exceptional circumstances, will probably occur with a frequency of less than 0.02 times per year (i.e. less than once in 50 years).
Unlikely	The event or hazard: could occur at some time, will probably occur with a frequency of 0.02 to 0.1 times per year (i.e. once in 10 to 50 years).
Possible	The event or hazard: might occur at some time, will probably occur with a frequency of 0.1 to 1 times per year (i.e. once in 1 to 10 years).
Likely	The event or hazard: will probably occur in most circumstances, will probably occur with a frequency of between 1 and 10 times per year.
Almost certain	The event or hazard: is expected to occur in most circumstances, will probably occur with a frequency in excess of 10 times per year.

The occupational safety and health qualitative measures of injury impact are then combined with the likelihood measures in Table 2.12 to place the proposed TTM installation in its appropriate cell in the risk matrix in Table 2.13 below, which shows the residual risk rating after precautions have been taken.

Table 2.13: Qualitative risk analysis matrix – residual risk rating (Main Roads Western Australia, 2022, p. vi)

	Consequence				
Likelihood	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost certain (A)	**Low 5**	**High 10**	**High 15**	**Very High 20**	**Very High 25**
Likely (B)	**Low 4**	**Medium 8**	**High 12**	**Very High 16**	**Very High 20**
Possible (C)	**Low 3**	**Low 6**	**Medium 9**	**High 12**	**High 15**
Unlikely (D)	**Low 2**	**Low 4**	**Low 6**	**Medium 8**	**High 10**
Rare (E)	**Low 1**	**Low 2**	**Low 3**	**Low 4**	**Medium 7**

These risks are then managed in accordance with the approach shown in Table 2.14.

Table 2.14 Management approach for residual risk rating (Main Roads Western Australia, 2022, p. vi)

Residual Risk Rating	Required Treatment
Very High	Unacceptable risk. **HOLD POINT**. Work cannot proceed until risk has been reduced.
High	High priority, Roadworks Traffic Manager (RTM) must review the risk assessment and approve the treatment and endorse the TGS prior to its implementation.
Medium	Medium Risk, standard traffic control and work practices subject to review by accredited AWTM personnel prior to implementation.
Low	Managed in accordance with the approved management procedures and traffic control practices.

2.6.4 Summary takeaways

Risk is the probability or exposure to a hazard, combined with the consequences of such exposure. Risk requires active management in accord with Safe System principles.

The major risks to road workers comprise risks from vehicles hitting road workers when unprotected on a live carriageway or when a vehicle veers off course and penetrates the protections afforded to the workers. Therefore, road worker risk reduction TTM strategies are aimed at:

- eliminating the need for workers to be on site as much as possible
- reducing risk further by minimising the numbers of workers required on site
- reducing as much as possible workers' exposure to risk when on site
- protecting workers as much as possible when they are on site.

This is seldom mentioned, but there is also a duty of care to vehicle occupants as their vehicles pass through TTM sites, including motorcyclists and cyclists. Non-roadworker pedestrians, including those using wheelchairs and mobility scooters, also require protection.

Risk matrices combine the likelihood of an event occurring with the severity of the consequences to calculate a risk level, which can then be used to determine whether the level of risk is tolerable. They relate to events so do not take the level of exposure to risk into account. This is dealt with by wherever possible removing or reducing the need for workers to be placed in risky situations over time.

Risk-based approaches to TTM use a hierarchy of controls, as illustrated by the pyramid of controls in Figure 2.9. Control measures are grouped into six categories according to ability to control the hazard and reduce risk. The hierarchy of controls is used to consider and then select appropriate control measures after determining the site risk level and considering the appropriate level of planning.

2.7 Risk associated with installing and removing roadworks equipment

ETSC (2011) has some important comments to make related to installation and removal of work zones. It states that:

> *The installation of a work zone can be seen as a small, short term work zone before the main works begins. The last part of a work zone is the removal part which should be seen as the reverse of the installation and covers carefully taking away the extra signage and barriers before leaving the carriageway over to live traffic.* (p. 23)

ETSC (2011) considers it a priority to make careful decisions around when barriers or other protection tools (like vehicles with crash cushions, shadow vehicles) should be used to protect road workers when they are installing and removing TTM equipment. It advocates the use of a decision tool to facilitate this decision-making process. Regarding infrastructure, ETSC holds that, during installation, signposting should be in accordance with general principles regarding signposting.

> *They must give road users gradual, consistent, and comprehensible warning of the type of obstructions and guide them on how to proceed in a safe manner.* (p. 23)
>
> *Installation of the work zone should take place at a time which is characterised by a lower traffic flow.* (p. 23)
>
> *Buffer zones and physical protection of workers are needed even during the preparatory phase. Traffic cones and other guidance and delineation equipment are no substitute for continuous physical protection measures.* (p. 23)

Speed restrictions need to be in place during installation and removal. Intelligent transportation systems can be used to inform drivers, and appropriate enforcement of speed limits is required. Western Australia has put provisions in place for lower than usual speed restrictions during such periods (Main Roads Western Australia, 2020). Advance warning of the preparation phase is necessary and should include signs as well as overhead gantries (in cases where the road has overhead gantries signs). Drivers' exposure to risk can be reduced by using fixed and mobile gantry signs, high-level nearside signs and lane-blocking vehicles.

In England, the Measurement of Injury Risk (MIRi) Index is used to measure risks related to installing and removing TTM equipment. It allows for exposure to risk by adding a third (exposure to risk-related) dimension to the 2-dimensional matrix. This is described in Fowler et al. (2011). The MIRi Index considers the risk involved in installing and removing various configurations and can be used to compare the risks related to those configurations. These actions comprise a large portion of TTM risk in England. English data quoted by Fowler et al. (2011) showed that for reported incidents between 2006 and 2010, 62 injuries and near misses (57.4%) occurred during the installation of TTM equipment, and 26 (24.1%) occurred during its removal (Table 2.15).

Table 2.15 Incident sub-type injuries and near misses, by TTM process, 2006–2010 (reprinted from Fowler et al., 2011, p. 20)

Incident Sub Type	Setting Out	Removal	Maintenance	Modification	Total
Fatality-Riddor	2	0	1	0	3
MOP (member of the public) taken from the scene to hospital	5	1	0	4	10
Major Injury	4	1	0	0	5
Lost Time > 3 days	12	4	4	1	21
Lost Time =< 3 days	1	2		0	3
Injuries - First Aid	1	0	2	0	3
Injuries - Medical Treatment	2	0	0	0	2
Injuries - Self/Non treatment	2	3	0	0	5
Near Miss	33	15	4	4	56
Total	62 (57.4%)	26 (24.1%)	11 (10.2%)	9 (8.3%)	108

This is somewhat different from an analysis of police-reported pedestrian crashes at TTM sites that was carried out in 2016 by WSP's legacy organisation Opus (Frith, 2016) using crash data from the previous 15 years. The study found that 39 of the 82 reports were related to road worker injury. These reports are summarised in Table 2.16 by the phase of the roadworks in which the road worker was involved.

Table 2.16 Police-reported pedestrian crashes involving road workers in New Zealand, by crash severity and TTM phase, 2001–2015 (data from the Waka Kotahi Crash Analysis System)

Crash severity	TTM phase			
	Installation	During TTM	Removal	Not sure
Fatal	0	0	0	0
Serious	0	15	0	0
Minor	0	21	0	3
Non-injury	2	6	0	0
Total	**2**	**42**	**0**	**3**

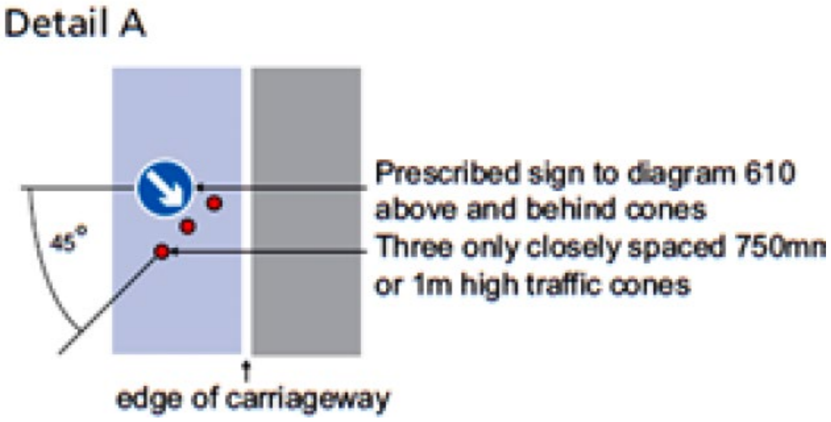
Where the phase was known, 42 out of the 44 crashes occurred during roadworks rather than the installation or removal phases. The two crashes identified as installation-phase crashes were related to the putting out of cones and no injury was recorded, although contact with a road worker occurred. There were no crashes identified as involving the removal of roadworks equipment. Four crashes involved stop/go sign operatives being hit. This is not an unexpected finding given that the installation and removal phases are relatively short compared to the length of active works. In saying this, however, injuries during these phases are still a concern, and it should be a high priority to keep workers away from active carriageways. In Australia there have been two road worker fatalities from the installation and removal phases recently reported in the media. In one, the road worker was packing up at the end of the works (Parsons & Maddison, 2021). In the other the worker was setting up the site (Kolovos, 2021).

Comparing with the UK experience, it is important to remember that most of the UK incidents were near misses rather than actual crashes as reported in New Zealand.

The MIRi Index is supplemented with a carriageway crossing value. This is based on an aggregated value of carriageway crossings to allow quantification of the reductions in carriageway crossings achievable through changes in working practices. The following five phases were considered in producing the index:

1. Installation of advance signing
2. Installation of 'Detail A' (as in Figure 2.10)
3. Taper installation (from Fowler et al., 2011, p. 24)
4. Taper removal (including the removal of Detail A)
5. Removal of advanced signing

Figure 2.10 Components and location of Detail A (reprinted from Fowler et al., 2011, p. 24)



To make meaningful comparisons of the risks involved with the installation and removal of equipment related to various roadworks configurations, the MIRi Index considers factors like probability levels, exposure and consequence severity. The following factors were considered in the development of the index.

- **Probability levels:** Road worker injury is infrequent and thus the probability of an individual worker being injured is low. The scale used for ranking risk reflected this by allowing the probabilities to be ranked over the full length of the scale. The probability scale was relative rather than absolute as the data to calculate absolute probabilities did not exist.
- **Exposure to the hazard:** An initiative may reduce road worker carriageway crossings by two, which over a 3-lane motorway may account to 18 seconds of exposure reduction. Therefore, a scale was needed that could detect a noticeable risk level change with a few seconds difference in exposure. A logarithmic scale was developed that would allow for a time range from a few seconds to several hours to be included on the same scale.
- **Consequences:** Expert knowledge was used to determine likely consequences of vehicle impact. A key consideration was the effect of vehicle type on road worker risk and the mechanism by which an impact on a worker could occur. This suggested a greater hazard to workers in nearside lanes due to the greater volumes of heavy aggressive vehicles using those lanes.

It was considered important to categorise risks into more than three levels so that movement between levels after the implementation of safety initiatives could be easily demonstrated. It also needed to be possible to calculate levels for individual sub-tasks and people and combine these to provide overall risk levels for each task and method. This was accomplished using numbered risk levels.

MIRi Index calculations from Fowler et al. (2011) showed that:

- eliminating the 200-yard and 600-yard advance signs and Detail A on the hard shoulder has the potential to reduce the MIRi Index by up to 22% and reduce carriageway crossings by up to 52%
- eliminating the need for offside signs in the event of nearside lane closures has the potential to reduce the MIRi Index by 28% and reduce carriageway crossings by 100%.

2.7.1 Summary takeaways

Installing and removing TTM equipment are dangerous activities while they are in progress. Therefore, it is worthwhile to measure their risk and attempt to limit as much as possible the exposure to risk of workers engaged in the activity.

British researchers developed the MIRi Index to provide such a metric. It considers factors like probability levels, exposure, and consequence severity. MIRi Index calculations from Fowler et al. (2011) showed that eliminating advance warning signs, Detail A on the hard shoulder, and offside signs in the event of nearside lane closures all have the potential to reduce the MIRi Index score and carriageway crossings.

2.8 The use of 'near misses' in measuring risk

2.8.1 On the road, what sort of near miss is a good risk indicator?

Road workers are seldomly reported injured from collisions with road vehicles, as can be seen from Table 2.15. This means that the use of near misses as an indicator of risk from road vehicles is required. However, it is a vexing problem to decide what level of 'near miss' relates best to the safety of a road worker. Glaze et al. (2020) state:

> *Inconsistencies in what suppliers report or identify as an incident or near miss has likely contributed to significant levels of under reporting.* (p. 4)

It could also be noted that equally, if definitions of near miss are too liberal, over-reporting with attendant avoidable costs may be happening.

The worker safety literature appears to contain no thresholds for reporting near misses. Various similarly based definitions of a near miss are given. An example is:

> *An incident which did not result in injury, illness, damage or other loss, but potentially could have.* (University of Auckland, n.d.)

It is obvious from the above quote that thresholds are very subjective if left to the individual person reporting, but it is also logical that at some threshold level of severity the frequency of 'near misses' will relate to the frequency of real crashes. To quantify this relationship, a metric that can be practically measured with a severity threshold level representing those 'near misses' that relate meaningfully to actual crashes is needed.

One of the first authors to address this problem was Hayward (1972). He called this metric a 'scale of danger' and proposed 'time to potential collision between the protagonists in the unsafe event' as a measure of seriousness. The time to collision (TTC) may be thought of as the time the drivers – or in the case of TTM, a driver and a pedestrian – have to take corrective action to avoid a crash. A near miss in this context is a traffic event with very short TTC that provokes some sort of evasive action.

After a study by human observers of intersection behaviour, Hayward (1972) recommended one second as a minimum TTC value, characterising any interaction with a TTC of less than one second as a 'near miss'. He then stated that the next step would be to correlate these 'near misses' to crashes.

The next development of importance was the Swedish traffic conflicts technique (TCT) (Hydén, 1987; Laureshyn & Várhelyi, 2018). This originally involved laborious surveys on site by observers, but any modern application would use a higher, more cost-effective level of technology. The definition of a conflict (or near miss) used by the Swedes emanated from Amundsen and Hydén (1977, cited in Laureshyn & Várhelyi, 2018) and read:

> *A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged.* (p. 2)

In other words, a collision course must be involved.

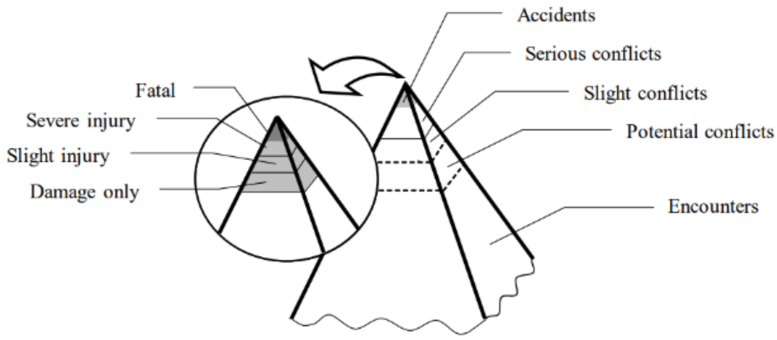
The basics of the Swedish TCT as listed in Laureshyn and Várhelyi (2018) are a:

- requirement for a collision course in a conflict
- definition of conflict severity based on the onset of an evasive action
- distinction between serious and non-serious conflicts.

Serious conflicts indicate breakdown in the interaction between vehicles or vehicles and pedestrians akin to that before a crash, meaning they can be used as crash surrogates.

The theoretical basis of the Swedish TCT is illustrated by the 'safety pyramid' in Figure 2.11. The lower part of the pyramid represents the normal, frequent and safe encounters between road users. The top of the pyramid represents encounters leading to fatal or injury crashes. These are very rare in relation to the total number of the events. In between is a gradation of interactions from potential conflicts to serious conflicts. The Swedish TCT, which involves human or technologically based observation of conflicts, is based on the premise that if the relationship between the severity and frequency of the events is known, it is then possible to calculate the frequency of crashes from the frequency of the more easily observable serious conflicts.

Figure 2.11 'Safety pyramid' (reprinted from Laureshyn & Várhelyi, 2018, p. 3)

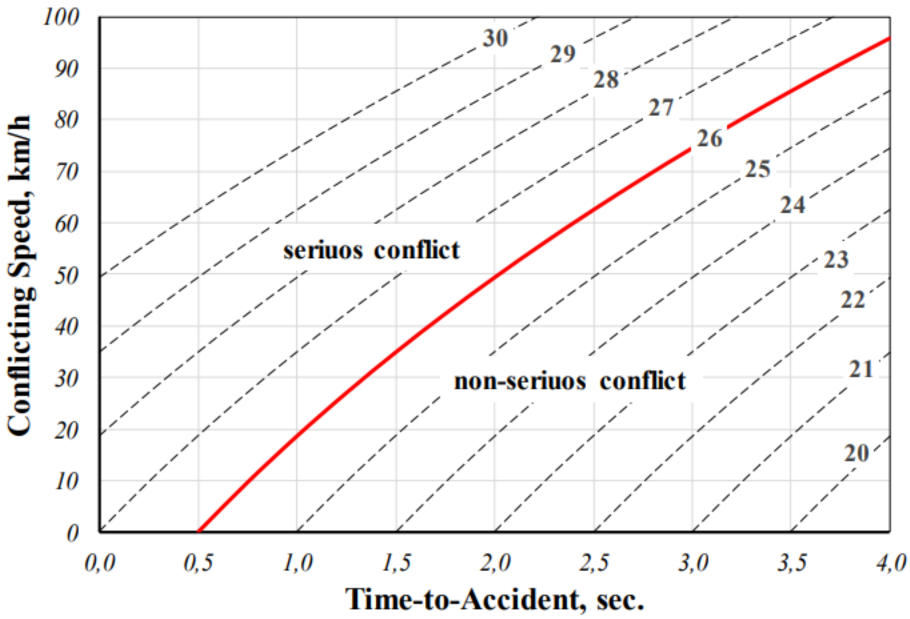


TTC before evasion occurs provides face validity as a measure of seriousness. However, it does not help greatly in assessing the actual injury risk from the avoided collision, and it is not obvious how the injury risk in situations where the collision was avoided can be estimated. The Swedish TCT includes the speed at the conflict point in the final grading of conflict severity which, at least partly, considers the severity of the potential consequences. The Swedish researchers included speed as a refinement after they had originally favoured use of a constant TTC value of 1.5 seconds in urban areas (Hydén, 1987). The TCT combines the two indicators as follows:

- ***Time-to-Accident (TA)*** *– time remaining to a collision when the evasive action is taken by the relevant road user*
- ***Conflicting Speed (CS)*** *– speed of the relevant road user when he/she takes the evasive action. TA describes the time remaining.* (Laureshyn & Várhelyi, 2018, p. 5)

Lower TA values indicate more serious conflict. A higher CS value impacts adversely on both the chances to avoid a collision and its outcome in terms of injury. Thus, higher CS values indicate a more severe conflict. The chart depicted in Figure 2.12 is used to determine the severity of a conflict from the CS and the TA. The solid line is the dividing line. When both conflict participants take evasive action at once, TA and CS are estimated for both, and the data for the one who produces the lower severity level is used.

Figure 2.12 Conflict severity chart (reprinted from Laureshyn & Várhelyi, 2018, p. 5)



In the case of TTM, we are mainly interested in vehicle–pedestrian conflicts, although vehicle–TTM vehicle collisions are also an issue. For vehicle–pedestrian conflicts, the CS is always the vehicle speed.

Matsui et al. (2011) looked at a sample of interactions between taxis and pedestrians where a crash between a car and a pedestrian walking in front of the car was avoided by the driver braking. Details were collected by the vehicle's drive recorder and its forward-facing video camera. The TTC was calculated from the speed of the car and the distance between the car and the pedestrian when the pedestrian first appeared on video. The average TTC was 1.7 seconds (*SD* 1.3 seconds). The authors compared the near-miss data with real-world pedestrian crash data. They found that in both near misses and crashes, approximately 70% of pedestrians at intersections or on straight roads were crossing in front of forward-moving cars. They concluded from this similarity of pattern that car-to-pedestrian accidents could be investigated from near-miss data, which included video capturing pedestrian behaviours.

Guo et al. (2010) define a 'near-crash' as:

> *Any circumstance that requires a rapid, evasive maneuver by the participant vehicle, or any other vehicle, pedestrian, cyclist, or animal, to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of the vehicle capabilities.* (p. 11)

Guo et al. (2010) then investigated the relationship between the occurrence of crashes and near crashes using data from the 100-Car Naturalistic Driving Study. An interesting result came from analysis of drivers' involvement in crashes versus near crashes for each of 234 drivers. The analysis used a Poisson model setup, as shown in Figure 2.13.

Figure 2.13 Poisson model equation (reprinted from Gou et al., 2010, p. 29)

$$y_i \sim Poisson(\lambda_i)$$

$$\log(\lambda_i) = \beta_0 + \beta_1 x_i,$$

where y_i is the number of crashes, λ_i is the expected number of crashes, x_i is the number of near crashes for driver I, β_0 is the intercept and β_i is the coefficient of x_i.

The model results are shown in Table 2.17.

Table 2.17 Results of regression mode (reprinted from Guo et al., 2010, p. 29)

	Coefficient	Standard Error	*p*-value
Intercept	-2.31	0.25	<.0001
Near-Crash	0.21	0.04	<.0001

It is apparent that the coefficient for near crashes is highly significant. This implies that for every near-crash involvement by a driver, crash involvement will increase by a factor of exp(0.21) = 1.23; that is, an increase of 23%. This implies a definite relationship between the two.

Also, among Gou et al.'s (2010) conclusions was that there is no evidence suggesting that the causal mechanism for crashes and near crashes are different, and that:

> *for small-scale studies with limited numbers of crashes, using near-crashes as surrogate measures is informative for risk assessment and will help identify those factors that have a significant impact on traffic factors.* (p. 50)

2.8.2 Summary takeaways

- Serious 'near misses' have a relationship to crashes so can be used as crash surrogates when crash data is sparse, as in the case of TTM. Non-serious ones cannot be used.
- The definitions of a serious near miss by different authors are similar.
- The seriousness of a near miss is a combination of vehicle speed and TTC.
- In the context of TTM, the relevant speed in vehicle–pedestrian conflicts is that of the vehicle.
- In urban settings, TTC for pedestrian crashes is around 1.5 seconds.
- Technology rather than on-site observers is preferred for accurate near-miss data gathering.

2.9 Measures related to novel TTM configurations

On occasion a novel TTM configuration may be required for which there is little or no prior experience. In such cases it is advisable to gather more extensive performance data than normal to feed the data back to the participants with a view to fixing any deficiencies promptly if they appear. Performance data of this type could include:

- worker interview surveys
- speed surveys of approaching vehicles and of vehicles as they traverse the work site
- surveys of serious near misses.

2.10 Risk reduction via exposure reduction

The best way to reduce risk is to avoid it. Thus, a key aspect of TTM safety is to avoid exposure to risk as much as possible. This may be done in several ways.

2.10.1 Strategically planning roadworks to minimise their impact

ETSC (2011) makes the point that safety, including worker safety:

> *should be a key consideration at all stages in the life cycle of any road related works project whether it be long, medium or short term or mobile.* (p. 11)

ETSC (2011) goes on to state (in summary):

> *Project planning, including the tendering process carried out by clients, should incorporate work zone safety risk assessment, impacts and mitigation measures as a matter of course.*
>
> *The issue of maintenance should be considered from the outset of the design stage in terms of new roads or proposed amendment/renewal of existing roads.*
>
> *…designers should investigate means of engineering out the need for maintenance and engineering in measures that support safe maintenance from the outset.*
>
> *The design of roads should be based on the principle of minimal intervention which tries to ensure that minimal changes to the original road structure will be required.*
>
> *Design that contributes to legibility and reduces the need for roads users to modify their behaviour should be a primary aim.* (p. 11)

Also important is timing and to avoid as much traffic as possible (Greenhalgh et al., 2012). This may involve night work.

Austroads (2021b) lists the following considerations for minimising impacts on road users:

- Minimise the length of road and paths on which traffic management is placed.
- Consider the right times to do the works.
- Minimise the time the road and path are occupied.
- Minimise blocked lanes and paths.
- Have realistic alternatives for all modes of transport.
- Consider coordinating with other works undertaken nearby.

This process is sometimes called Safety in Design and has been defined by the Stronger Christchurch Infrastructure Rebuild Team (2016) as:

> *a process that integrates hazard identification and risk assessment methods early in the design process, to eliminate, isolate or minimise the risks of injury to those who will construct, operate, maintain, decommission and demolish the asset.* (p. 10)

2.10.2 Traffic demand management

Traffic demand management can be used to reduce traffic volumes through the TTM site and thus reduce exposure to risk at the site (National Cooperative Highway Research Program (NCHRP), 2008). This can include such tactics as diverting traffic via alternative routes either by static signing or in real time, ramp metering and encouraging car-pooling and active modes where they are safely able to use alternative routes.

2.10.3 Accurately informing drivers of site characteristics

Exposure to risk of workers is reduced if all aspects of the site relevant to driver behaviour as they approach the site are effectively communicated to drivers. This means that the following need to be at the forefront of Safe System best practice (see also section 2.5.1):

- signage quality
- lighting quality
- speed limit appropriateness
- quality of the physical approaches in terms of road safety engineering and driver psychology.

2.10.4 Reduction of signage to reduce live lane foot traffic

2.10.4.1 Elimination of the need for workers to cross live motorway carriageways on foot

This was achieved in the UK by using a ‘temporary traffic management signs simplification technique’, which eliminated 40% of the advance warning signs needed for short-duration roadworks. This eliminated an estimated 46% of all carriageway crossings.

2.10.4.2 Elimination of short-duration signage on central reservations

In the UK, the former Road Workers’ Safety Forum (RoWSaF) was a wide-ranging group of government and industry representatives, under the auspices of Highways England, with an interest in road worker safety. Its core business was to reduce road workers’ exposure to risk from traffic. The British initiatives, which are accompanied by well-defined targets in the RoWSaF strategy of 2015 (Road Workers’ Safety Forum, 2015), include the following.

- An offside signs removal (OSSR) technique was developed which eliminates all central reservation signing at short-duration roadworks. At the time of writing (2015), 95% of short-duration lane closures could use OSSR. The remaining closures were being undertaken either as a monitored OSSR roll out or by using temporary workarounds in wait of further innovation.
- A series of simulator and on-road trials were conducted to understand the impact on driver behaviour. These indicated that road user safety would be unaffected. The parts of these trials that have been made publicly available are described in Palmer et al. (2014). This work resulted in the production of an interim advice note (see Highways England, 2016) allowing the omission of central reservation signage at short-duration roadworks on two-, three- or four-lane dual carriageway roads.
- A target was set to eliminate the need for road workers to be on foot on a live carriageway by December 2016.

It is not clear to what extent progress was made towards reaching this target.

Recent changes in the UK mean road workers should only be on foot on a live carriageway when setting out traffic management from the hard shoulder on motorways or installing TTM equipment within lead-in zones (chicanes) and around junctions (splitters). Otherwise, the policy is to protect workers with an impact protection vehicle, which effectively closes the lane. Work is ongoing to find ways to eliminate the remaining cases where workers still need to be on foot in a live carriageway. Some of this work is described in Palmer et al. (2015).

The changes were preceded by a programme of research carried out by the Transport Research Laboratory (TRL). This work was prompted by unpublished internal TRL work by Baguley (1996), which had identified that there was some scope to simplify TTM and reduce the number of signs. The work covered several situations around roadworks.

The first piece of work related to single-lane closures on dual carriageway roads subject to the national speed limit of 70 km/h and featured three alternatives to the layout described in Chapter 8 of the Department for Transport's (2009) *Traffic Signs Manual* (referred to here as the 'Chapter 8 layout'). The research as described in Wood et al. (2011) involved three stages. First, there were stakeholder workshops at which various less sign-intensive alternatives to the Chapter 8 layout were canvassed. The Chapter 8 layout is illustrated in Figure 2.14.

Alternative layouts are illustrated in Figure 2.15. These three alternatives were then tested against the Chapter 8 layout in the TRL simulation facility. They represented what was described as 'minor change' (layout 1), 'moderate change' (layout 2) and 'large change' (layout 3). During the simulations of vehicle runs through the simulated work sites, data related to the measurement of vehicle control and driver visual behaviour was gathered.

The simulation indicated that driver behaviour was relatively consistent over the four configurations with the following specifics:

- Drivers' following distances were independent of whether they were in the roadworks section.
- All drivers in the lane to be closed merged into the appropriate open lane at least 200 metres before the cone taper, suggesting they understood what was required of them.
- Drivers reduced their speeds at the roadworks.

These results led to a finding that any of the alternatives would be suitable and a recommendation to field test layout 1, which could be implemented simply using existing risk assessment procedures with no requirement for new equipment or signs. Layout 1 (1A in Figure 2.16) was trialled along with a variant (1B in Figure 2.16) where two 200 m 'wicket' signs were removed. Layout 1B was planned to be trialled only if layout 1A was deemed to be successful, which it was.

Figure 2.14 The 'Chapter 8 layout' of the lane change zone for a single-lane closure on a dual carriageway road for which the national speed limit applies (reprinted from Department for Transport, 2009, p. 179)

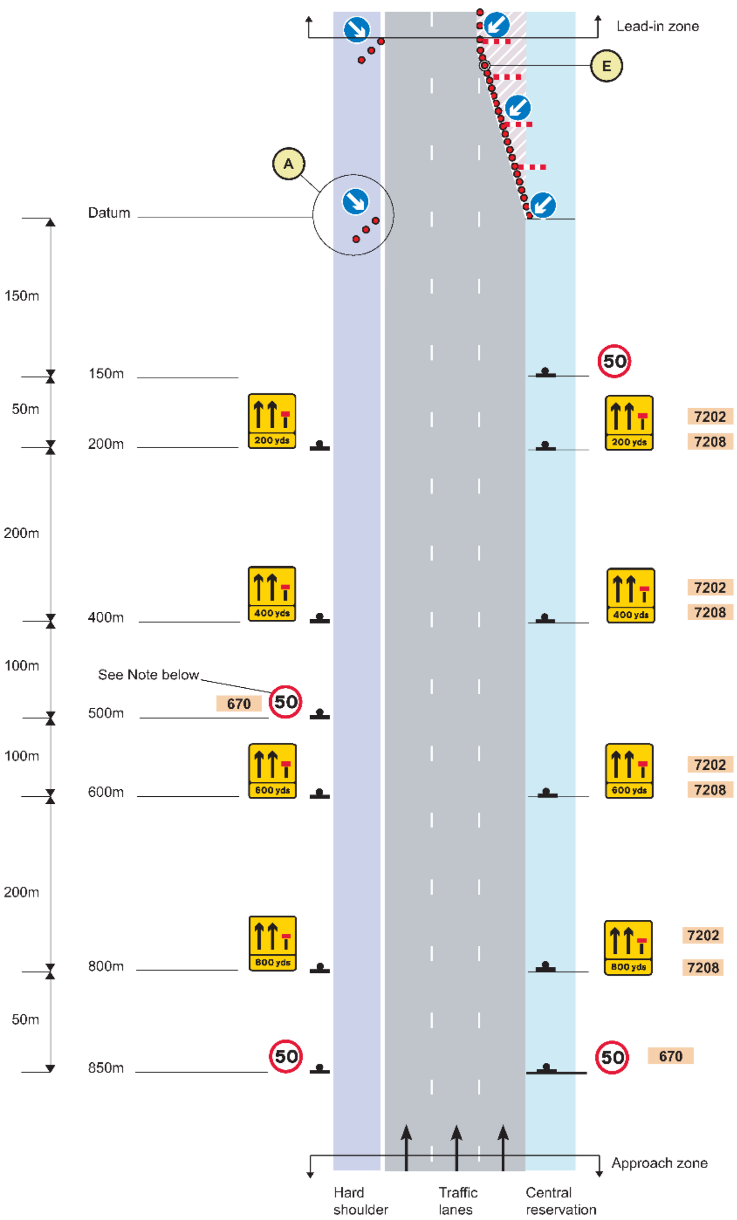
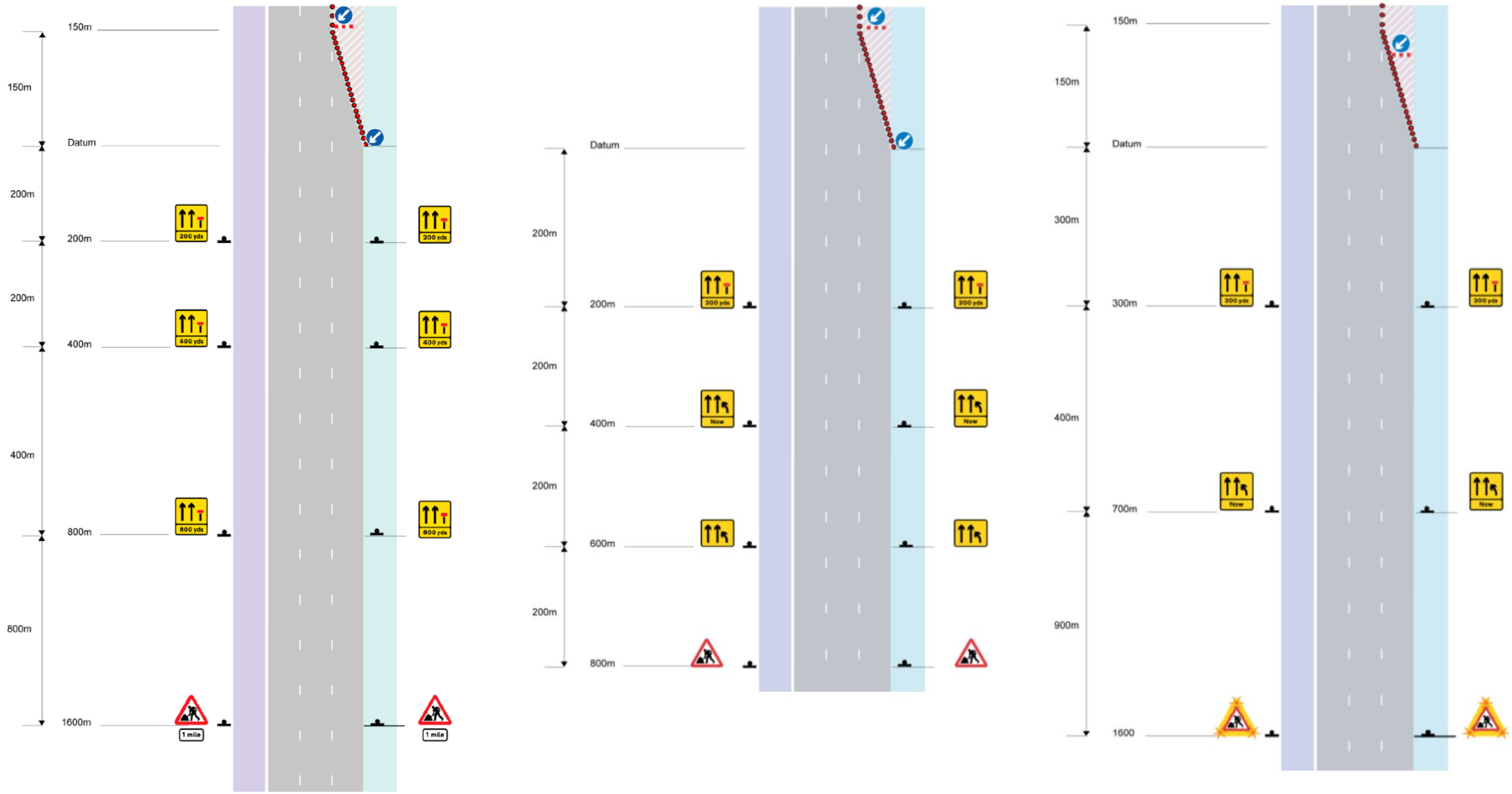


Figure 2.15 Alternative layouts for single-lane closures on dual carriageways (reprinted from Wood et al., 2011, pp. 7–9)

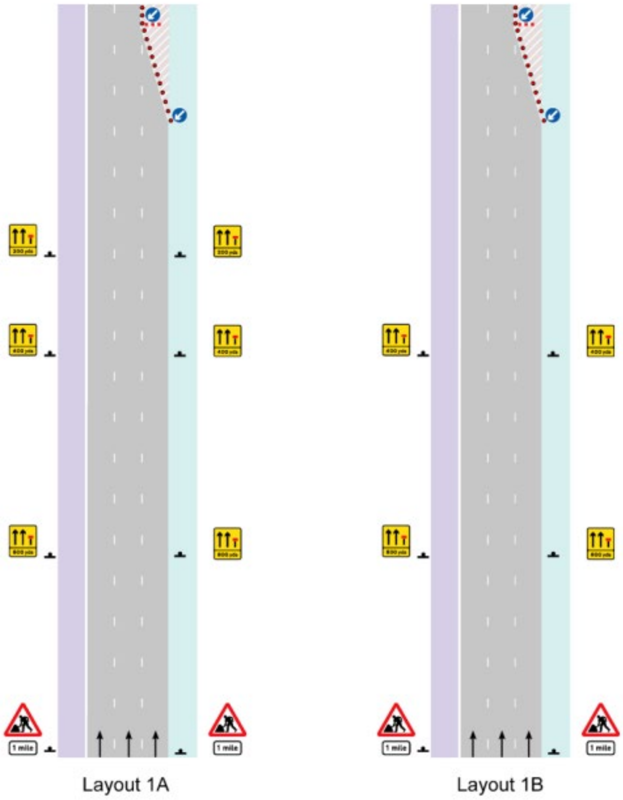


Layout 1 – minor change

Layout 2 – moderate change

Layout 3 – large change

Figure 2.16 Two alternative lane closure layouts trialled (reprinted from Wood et al., 2011, p. 14)



The on-road trial used an ANOVA (analysis of variance) to identify the impact of the different options on lane change behaviour with special attention to vehicles in the third lane about to be closed. The relevant results were as follows.

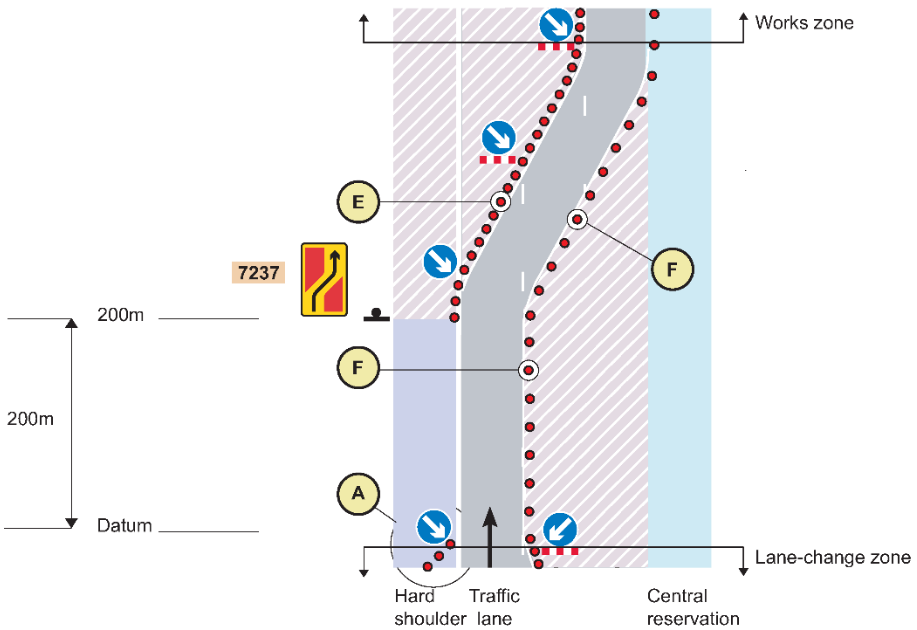
- Overall, there was a significant reduction in the number of vehicles in the lane to be closed by the 200 m point.
- The pattern of vehicles moving lanes did not differ significantly between the three configurations.

Given the relatively large sample size, it can be taken from these results that it is very unlikely that there is any difference in the distribution of vehicles exiting the third lane over the three configurations.

The alternative configurations were then looked at from the point of view of the MIRi Index (Fowler et al., 2011). It was calculated that, compared to the Chapter 8 layout, layout 1A reduced worker risk (as measured by the index) by 14%, along with 35% fewer carriageway crossings. With layout 1B, the risk reduction was 22%, with 52% fewer carriageway crossings. It was concluded that by using layout 1B, a substantial reduction in carriageway crossings and road worker injury exposure could be achieved.

Further trials were carried out by TRL (Palmer et al., 2014) of configurations of advance warning signage where no signage was placed on the central reservation, thus obviating the need for road workers to cross the carriageway to install/remove such signage. Another strand of this work is described in Palmer et al. (2015). This relates to the major risk to workers not addressed by the work described above. This is the risk to workers during installation of the lead-in zone coning for a single-lane changeover on a high-speed dual carriageway road that moves the traffic from the nearside open lane to the offside lane, or vice versa. The situation of movement from a nearside lane to an offside lane is illustrated in Figure 2.17. The opposite movement may also occur.

Figure 2.17 Lead-in zone for a single-lane changeover on a high-speed dual carriageway road (reprinted from Department for Transport, 2009, p. 191)



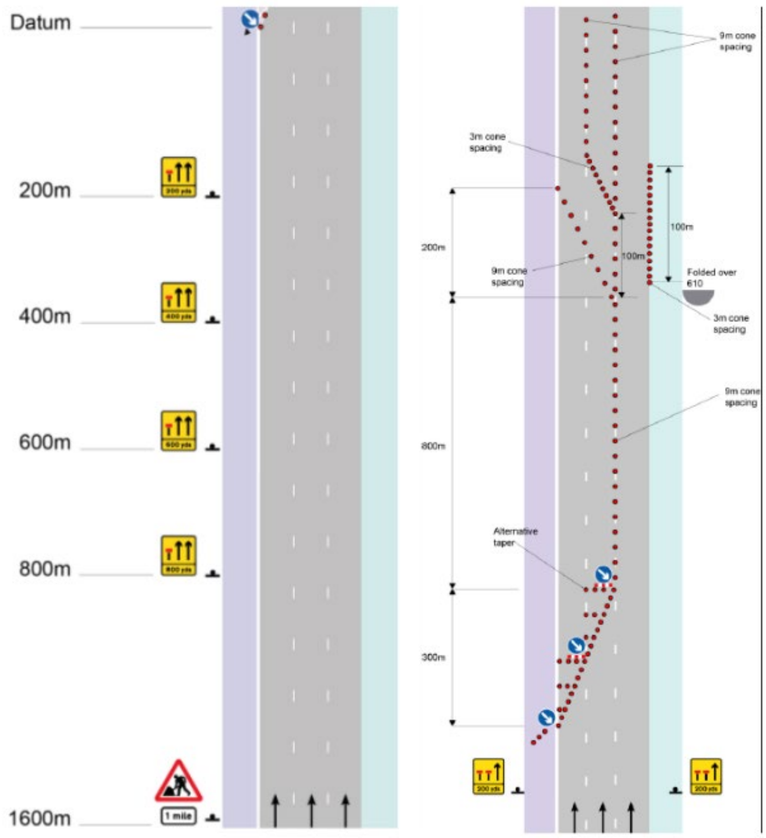
To install the ‘facing wall of cones’, workers must enter the only remaining open lane in the face of oncoming traffic, utilising what gaps they can find in the stream – a risky activity. If the work zone is left with the wall incomplete due to the low traffic window of opportunity passing, risk to road users is heightened due to the incomplete lead-in zone.

To mitigate this risk, National Highways found that, through a series of trials, blocking the lanes for sufficient time (25–30 seconds) to allow the workers to carry out the work was possible using an attenuator truck in the outside lane equipped with a legal ‘no overtaking’ sign. This vehicle is illustrated in Figure 2.18.

Figure 2.18 Attenuator truck in England equipped with a ‘no overtaking’ sign (reprinted from Palmer et al., 2015, p. 9)

In these trials, road workers placed cones and signs to create the initial 'facing wall' used to close the lane. This involved live lane work during which the workers were protected by the sign on the truck, which created a traffic-free window. This was achieved by the truck moving slowly down the outside lane at speeds between a maximum of 40 mph and 20 mph to provide the appropriate protected time window. The method was considered good notwithstanding some concern about the manoeuvring of the attenuator truck into the outside lane – an issue that was unresolved at the time the report was written. This system would be suitable for the installation or removal of the cones. The experimental layout is shown in Figure 2.19.

Figure 2.19 TTM layout used during trials, consisting of offside signs removal advance signing (left) and 'alternative' taper, longitudinal coning, and lead-in zone (right) (reprinted from Palmer et al., 2015, p. 15)



To summarise, National Highways (England) now has three separate initiatives that when taken together represent a considerable improvement in the safety of road workers. They apply to the 'Strategic Roads Network', which comprises motorways and major A roads, which are normally at least dual carriageway standard. The initiatives are:

- the employment of a 'temporary traffic management signs simplification technique', which eliminated 40% of the advance warning signs needed for short-duration roadworks on dual carriageways and motorways – this eliminated an estimated 46% of all carriageway crossings
- an OSSR technique, which eliminates all central reservation signing at short-duration roadworks
- a technique for using a moving attenuator truck to protect workers while setting up and taking down lead-in zones on three-lane dual carriageways and motorways.

2.10.4.3 Use of reboundable posts instead of cones

Reboundable posts are delineator posts that rebound after being hit, which reduces the need to place workers at risk by having them replace cones. Obviously, as these devices need to be screwed into the road surface, their use will be confined to longer-duration temporary works where the changes associated with the works are always in force, whether workers are present or not.

2.10.5 Reduction of inappropriate vehicle speeds

2.10.5.1 Speed-related risk

Speed is an important factor in crashes at TTM sites. Between 2001 and 2015 inclusive, 18% of all injury and non-injury crashes involving TTM had speed as a causative factor (Frith, 2016).

The European PREVENT study (as quoted by ETSC, 2011, p. 5) stated that:

> *the most consistent finding is that speeding is common at roadworks… (and)…the majority of drivers drive too fast when approaching roadworks.*

A French study cited by ETSC (2011) found that 44% of road users were speeding in the vicinity of roadworks (excess speed at least 20 km/h), with 20% failing to preserve safe distances from other vehicles.

The speed limits imposed at TTM sites should be consistent with Safe System speeds for situations in the presence of pedestrians. The International Transport Forum (2016) notes that a Safe System speed is defined as the impact speed where the chance of a fatality is 10% or less and states this to be 30 km/h in the presence of pedestrians who, in the case of TTM, are road workers. Injury related to impact speeds is not an exact science. Tefft (2011) found that while the 10% risk of death threshold for pedestrians was reached at 37 km/h, the 10% risk of severe injury was met at 26 km/h. Jurewicz et al. (2015) found that a 10% risk of a serious injury would be reached at 20 km/h. Therefore, the Safe System speed is somewhat of a practical compromise.

Precisely estimating impact speed is difficult because it relies on the crash report of the police officer at the scene, and they often rely on what the driver and/or the pedestrian tells them. The posted speed limit is not a good proxy for the impact speed, mainly because it does not consider a driver's reaction time, or that they may have been travelling above or below the speed limit.

The weight of the vehicle is clearly an important variable in considering the speed-related risk. Heavy vehicles operating through TTM sites increase the risk to exposed road workers due to their sheer mass.

2.10.5.2 Treatments evaluated by Richards et al. (1985)

Richards et al. (1985) conducted studies at six Texas work zones: two rural freeway sites, one urban freeway site, one urban arterial site, and two rural highway sites. The following speed control methods were studied:

- flagging (flagger, equipped with a paddle or flag, signals traffic to slow)
- law enforcement (deployment of Police Patrol)
- changeable message signs
- effective lane width reduction
- rumble strips
- conventional regulatory and advisory speed signing.

The treatments evaluated are shown in Table 2.18.

Table 2.18 Speed control treatments evaluated by Richards et al. (reprinted from Richards et al., 1985, p. 68)

Speed Control Method	Treatment	Description
Flagging	MUTCD procedure	Flagger equipped with red flag and orange vest performed "Alert and Slow" signal detailed in Part VI, MUTCD.
	Innovative procedure	MUTCD "Alert and Slow" signal enhanced by two additional movements: (a) flagger motioned traffic to slow with free hand then (b) pointed with free hand to nearby speed sign.
Law enforcement	Stationary patrol car–lights and radar off	Marked patrol car parked on side of road parallel to traffic.
	Stationary patrol car–lights on, radar off	Marked patrol car parked on side of road parallel to traffic with flashing red and blue lights on.
	Stationary patrol car–lights off, radar on	Marked patrol car parked on side of road perpendicular to traffic with radar on and pointed toward traffic stream.
	Circulating patrol car[a]	Marked patrol car continuously driven back and forth through work zone without lights or radar on.
	Police traffic controller	Uniformed officer standing on side of road next to speed sign and manually motioning traffic to slow down.
CMS	Speed and informational message	One- or three-line bulb matrix sign displaying work zone information message plus a speed advisory.
	Speed message only	One- or three-line bulb matrix sign displaying speed advisory.
Effective lane width reduction	Cones (12.5 ft)	On two-lane highways, cones deployed to funnel traffic through a 12.5-ft-wide travel path. On multilane highways, cones positioned along the pavement edges leaving a 12.5-ft travel path between the cones and lane lines.
	Cones (11.5 ft)	Same as above except the travel path width decreased to 11.5 ft.
Conventional signing	Regulatory signing	Black-on-white regulatory speed sign with the desired work zone speed.
	Advisory signing	Black-on-orange advisory speed sign with the desired work zone speed.
Rumble strips[a]	8 strips–decreasing spacing	Eight 1/2-in.-high, polycarbonate strips installed across the travel lane with decreasing spacing, perpendicular to the travel direction.

[a]Tested only on 2-lane highways.

It was found that the best results came from flagging and law enforcement. The most effective flagging treatment reduced speeds an average of 19% for all sites, and the most effective law enforcement treatment reduced speeds an average of 18%.

The most effective changeable message sign and lane width reduction treatments each reduced speeds by only 7%.

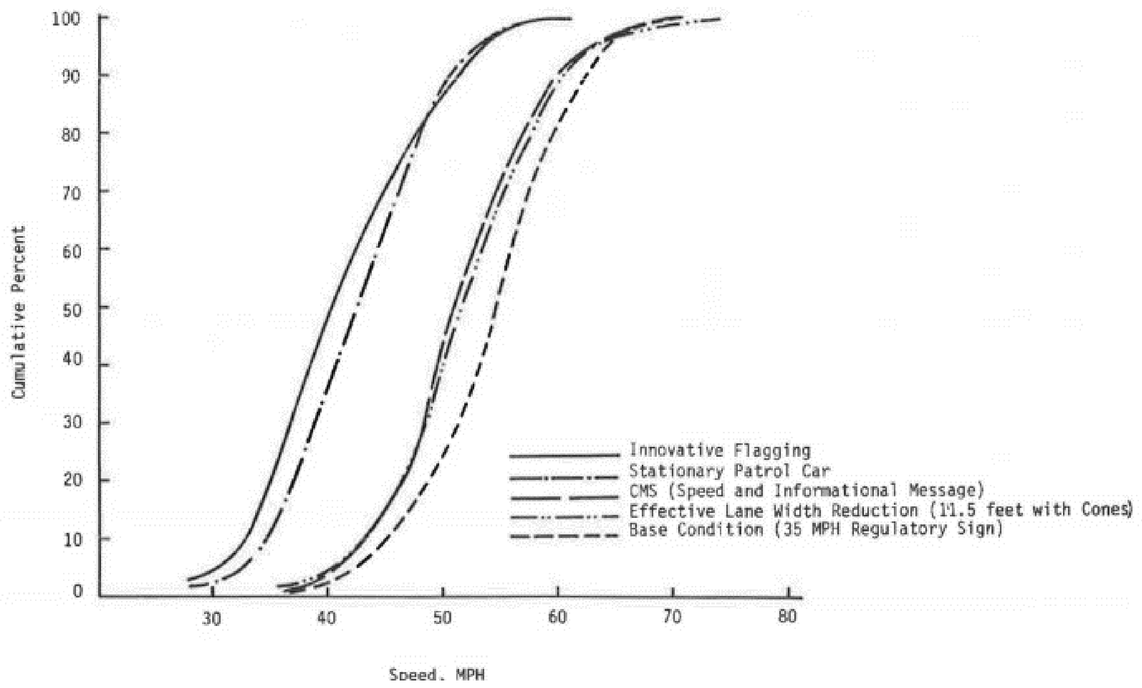
An innovative flagging procedure, a police traffic controller, and a stationary patrol car were found to be the most effective treatments on most highway types.

A circulating patrol car and rumble strips were found to be ineffective treatments for controlling work zone speeds.

Conventional regulatory and advisory signing were found to be ineffective in reducing work zone speeds, but their presence is still essential as they provide essential information.

Figure 2.20 depicts the cumulative speed distributions at the sites for a selection of the treatments.

Figure 2.20 Cumulative speed distributions of selected speed control treatments at an urban freeway site (reprinted from Richards et al., 1985, p. 76)



2.10.5.3 Cone configurations

Allpress and Leland (2010) evaluated two novel speed control interventions at a New Zealand open road TTM site where drivers were required to decrease their speed from 100 to 50 km/h. The two interventions were at the site entrance and required drivers to pass between a 3.5 m wide passage of either evenly or decreasingly spaced cones (see Figure 2.21).

Figure 2.21 Diagram of work site showing position of cones (reprinted from Allpress & Leland, 2010, p. 379)

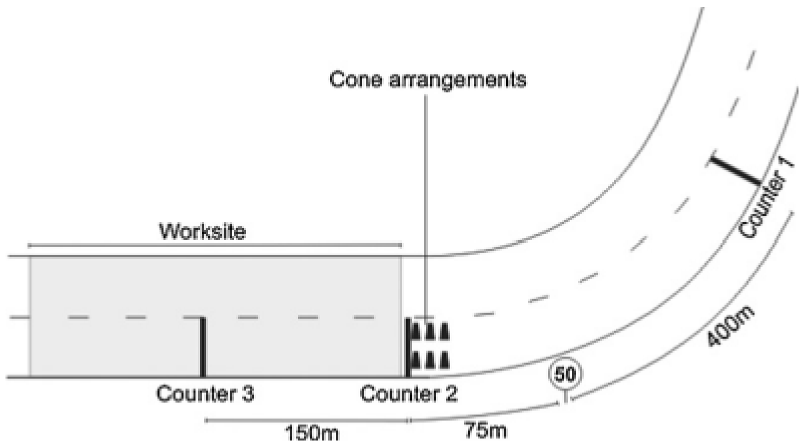


Table 2.19 Speed counting site results (reprinted from Allpress & Leland, 2010, p. 380)

	Counter 1	Counter 2	Counter 3
Even	94.04	62.30	53.77
Uneven	93.71	60.67	55.26
Baseline	94.60	70.14	57.51

Both interventions were highly effective at reducing speed (see Table 2.19). The greatest initial decrease in speed was 9.47 km/h below baseline for the uneven arrangement. Both arrangements more than halved the proportion of speeders travelling faster than 20 km/h over the speed limit. This indicates that of the two effective arrangements, the uneven configuration was the better choice. It is worth noting that neither configuration reduced the speeds to the level of the speed limit.

2.10.5.4 Average speed cameras

Average speed cameras are mentioned by ETSC (2011) as a viable method of enforcing speeds. ETSC (2011) cites UK experience indicating that such cameras may be used for both long- and short-term (overnight) works. As well as in the UK, average speed cameras are used at TTM sites in Belgium and Austria (Várhelyi et al., 2019). Várhelyi et al. (2019) interviewed Austrian experts who stated that:

> *the use of average speed control leads to a homogenisation of traffic flow, thus enhancing safety within the work zones*. (p. 35)

There are, however, constraints on the lengths able to be used with average speed cameras as the average obtained must be of sufficient accuracy to satisfy prosecution criteria. This means in practical terms a minimum length of around 2 km. Below this length, mobile cameras could be used, either vehicle based or temporarily fixed at the roadside.

2.10.5.5 Immediate feedback of speed

Immediate feedback of speed is mentioned in both ETSC (2011) and Várhelyi et al. (2019). Portable radar speed monitoring/display units usually mounted on a sign or on a trailer are used (see Figure 2.22) to inform motorists of their speed. In some cases, registration numbers are shown.

Figure 2.22 Immediate speed feedback signs (reprinted from Várhelyi et al., 2019, p. 34)

2.10.5.6 Appropriateness of approaches to TTM

Approaches to TTM need to be designed appropriately to achieve appropriate speeds. Speed control signs should be easily understood and placed so that drivers can comprehend their meaning in time to slow down before reaching the TTM installation. The temporary lane configurations and such features as well signed speed humps can also be considered. Variable message signs can change the speed limits as the requirements of the TTM change.

2.10.6 Digitisation of TTM

2.10.6.1 Introduction

Digitisation of TTM means using sensors on TTM equipment like cones and barriers so that any strike or disturbance can instantaneously be relayed to controllers. According to Highway Resource Solutions (HRS, n.d.) this reduces the need for routine inspections, thereby increasing safety and reducing greenhouse gas emissions by reducing travel. Also, TTM information without such sensors uses non-real-time manual call-in processes, which are subject to change and human error.

> *This can lead to misinformation, poor communication, delays and ultimately dissatisfied road users*. (p. 2)

2.10.6.2 Quick reporting of incidents without in-person inspections

In the UK current best practice requires the inspection of all TTM equipment every 2–4 hours. By allowing the equipment itself to report a failure or incident, much can be gained by not needing to do such inspections. According to HRS (n.d.):

> *On a single large Type A scheme, mandatory inspections could equate to over 260,000 miles travelled per annum with a carbon footprint in excess of 100,000 kg, just to visually inspect signs and cones.* (p. 2)

Also, looking to the future, these inspections can provide this information directly to connected vehicles, warning them of possible hazards and/or blockages ahead.

> *This technology works by creating a **digital twin**[5] for each work zone to deliver targeted safety alerts, automated remote monitoring of safety critical assets, real-time information of roadworks deployments and dynamic speed management.* (p. 5)

The digital twin is produced by creating a geozone corresponding to the roadworks area. Opportunities provided by this include:

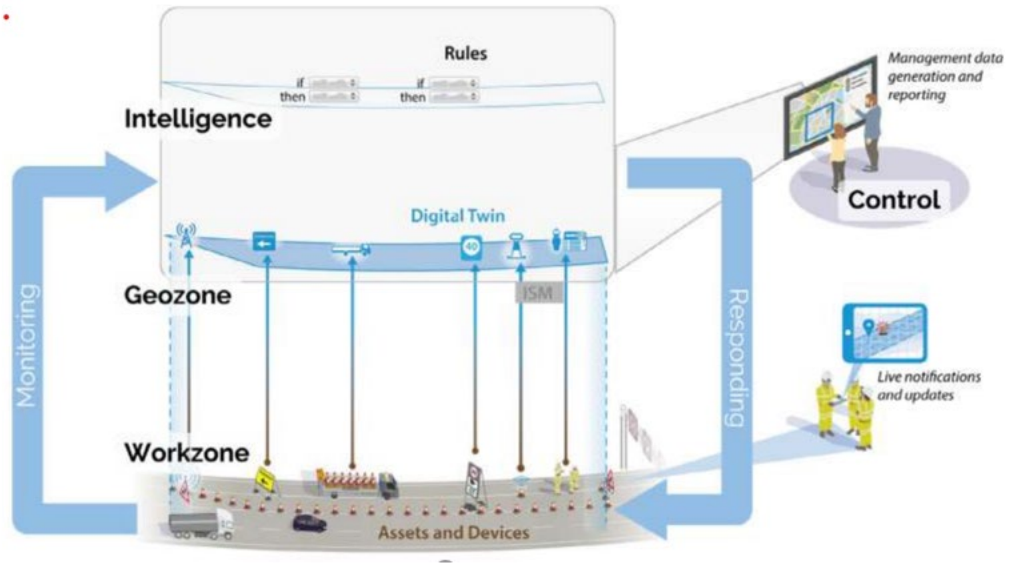
- automatic information flow direct from site to decision makers and stakeholders
- remote monitoring and control of safety critical assets.

Major benefits include:

- reduced visual inspection requirements and improved response time to incidents
- accurate reporting and time stamping for better decision making and provision of hotspot maps
- automatic communication of network occupancy information to road users, improving journey times and experience.

Figure 2.23 describes HRS's device management system, including all the interactions within the ecosystem created.

Figure 2.23 HRS's platform involving a digital twin for each site, enabling a fully automated ecosystem to manage and monitor safety critical TTM and other work zone assets (HRS, n.d., p. 5).



2.10.6.3 Case studies

Prompt reinstatement

Chevron Traffic Management (UK) has described how a taper strike (Figure 2.24) at a TTM site on the A45 Chowns Mill Improvement Scheme, which took out 50 cones and eight sequential lamps, was reinstated (Chevron, 2021).

[5] A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making (International Business Machines Corporation, n.d.).

Figure 2.24 Result of taper strike at TTM site on the A45 Chowns Mill Improvement Scheme (reprinted from Chevron, 2021, p. 1)

The TTM involved three permanent lane closures to increase the working area. HRS Intellicone Smart Taper was used as an enhanced safety measure. This provides immediate digital notification of any strike. The metric for determining success was time to reinstatement compared to time to reinstatement without the smart cones.

On 11 February 2021, a taper strike occurred. Table 2.20 describes the response sequence, which shows that it took only 58 minutes from taper strike to reinstatement.

Table 2.20 Time sequence from taper strike to rectification (adapted from Chevron, 2021)

15.11	Taper strike occurs
15.11	Traffic Safety and Control Officer receives alert advising of location and damage caused by strike
15.12	Traffic Safety and Control Officer receives deploys maintenance crew to taper
15.14	Maintenance crew requests Impact Prevention Vehicle (IPV) to support reinstatement of taper
15.20	IPV and Maintenance meet to cross-load cones to replace damaged cones
15.29	IPV cover deployed in live lane to allow taper reinstatement to commence
16.08	Taper secured and fully operational IPV and Maintenance crew leave site

Protection of workers from intimidation by road users

In the UK, Network Rail was concerned that previous closures of the Thorpe Bank level crossing near Doncaster for essential maintenance works had been accompanied by hostile behaviour from road users. This led to an innovative closure implemented by Chevron Traffic Management aimed to minimise interaction between rail workers and road users. A digital enclosure was created using Intellicone portable site alarms (PSAs), customer communication terminals (CCTs) and closed-circuit television (CCTV). These measures eliminated threats and confrontations between workers and road users.

The scheme involved four digital closure points; two were set up at each side of the level crossing. The outer closure points were equipped with an Intellicone PSA, CCTV, and a CCT with a quick response (QR) code. Members of the public were encouraged to use the CCT intercom or the QR code to gain information. The Intellicone PSA sounded if the closure was breached to deter people from proceeding any further.

The inner closure points were manned and fitted with a red Intellicone PSA. They were activated by workers who pressed an alarm button that activated the workforce Intellicone PSA at the level crossing. If this alarm sounded, rail workers had time to evacuate themselves from the danger zone. Figure 2.25 depicts the outer closure point.

Figure 2.25 Outer closure point with a group of road users (reprinted from Chevron, n.d., p. 2)

Automatic deployment of TTM equipment

TRL (Glaze et al., 2020) identified several high risk TTM activities suitable for automation. Using technology to automate the installation and removal of TTM equipment can reduce the need for operatives to enter the carriageway, which in turn removes the need for dedicated impact protection vehicles and reduces the likelihood of collisions between road users and such vehicles. Three areas were identified as being candidates for improvement by automation:

1. installation and removal of traffic management within the carriageway
2. installation and removal of traffic management on carriageways with no hard shoulder
3. installation of ‘splitter details’ within roadworks.

The report also identified several potential solutions, including:

1. Automated taper

The Versilis SwiftGate solar-powered automated taper module is designed to reduce the use of workers, and thus the risk to workers manually installing lane closures and tapers. The gate pivots horizontally from its mounting. Several gate modules may be used on a carriageway and are programmable to operate individually, sequentially or in groups. The gates can be coloured and reflectorised to suit the situation in hand, and flashing LEDs can be installed. The module can be monitored and controlled remotely by radio frequency unit, mobile phone or via the web. Figure 2.26 shows one of a series of gates used in a UK trial.

Figure 2.26 SwiftGate remotely deploying gate (reprinted from Fossdyke, 2022)

The operation of the gates can be remotely coordinated with upstream signage changes, SwiftGate can be deployed in approximately five minutes, faster than the time required for road workers to deploy a taper of cones to direct drivers away from the closed lane and dispensing with the use of such workers, with attendant safety gains. After deployment, cones can be placed behind the gates to separate the closed off lane from the other lanes without workers entering the live lane. The operation of the gate can be coordinated electronically with variable message signage and moveable signage.

In New Zealand, SwiftGate is used on a permanent basis on a peak-hour-only motorway on-ramp near the Victoria Park Tunnel in Auckland to close the on-ramp at off-peak times (Versilis., n.d.) (see Figure 2.27).

Figure 2.27 SwiftGates at part-time on-ramp near Victoria Park Tunnel (reprinted from Versilis, n.d.)

2. Remotely operated TTM variable message system

Installing lane change signage in advance of TTM is a source of risk to workers. This risk can be reduced by using temporary variable message signs (often trailer-mounted) to change the message remotely depending on the circumstances. This, of course, will not bring the risk to zero as the signs still need to be installed and removed. Figure 2.28 depicts a trailer-mounted Nissen VarioSign variable message sign.

Figure 2.28 Trailer-mounted Nissen VarioSign variable message sign (reprinted from Nissen, 2018, p. 24)

3. Automation of set down and retrieval of cones

On-road exposure of road workers setting down and retrieving cones can also be reduced using machines that can do the work (or part of the work) automatically. Such machines exist in North America, the UK and Europe. Their market penetration is unknown. An example is the cone placement and retrieval vehicle developed by the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT) (see Figure 2.29). Its development is described in detail in the business case written for progressing past the prototype stage (AHMCT, n.d.). Other such machines have been developed. Another, about which there is no research information, may be viewed on the AHMCT (n.d.) website.[6]

Figure 2.29 AHMCT cone placement and retrieval vehicle (reprinted from AHMCT, n.d.)

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[6] See http://legacy.ahmct.ucdavis.edu/projects/cone-machine/

AHMCT (n.d.) produced a prototype that enabled a single driver/operator to place or retrieve up to 100 cones. A higher-capacity 300-cone machine was also developed. In 2005, a commercial machine was produced based on the AHMCT design and is being evaluated in Caltrans operations. A detailed description of the prototype may be found in Lee et al. (2004).

In addition to these automatic machines (which have come out of the USA), a semi-automatic machine – the Conemaster (Figure 2.30) – has been developed and trialled in Britain (Highways Agency, n.d.). It is semi-automatic as it requires road workers on the back of the truck to handle the cones as they are delivered to or retrieved from the road. It thus has the safety advantage of keeping workers off the road, but the workers are still exposed to the hazards of working from the back of a truck. It is required to operate behind an attenuator truck for protection, which means four people are needed – three on the cone master and one to drive the attenuator truck. The trial found that the Conemaster completed single-lane closures quickly and safely with minimal road worker exposure on the road. The system performed with more difficulty in more complex situations. It requires two attenuator trucks when more than one lane is closed if road worker presence on the carriageway is to be avoided. It worked with least risk for offside lane closures.

Figure 2.30 Conemaster cone deposit and retrieval system (reprinted from Highways Agency, n.d., p. 3)

A less cumbersome Dutch semi-automatic system, the Verheij 4012, still requires a worker on the back of the truck (Figure 2.31).

Figure 2.31 Verheij 4012 cone placement and retrieval system (reprinted from Verkeersnet, 2012)

4. Autonomous impact prevention vehicle (IPV) (known in New Zealand as an attenuator truck)

The UK company Colas has produced the first autonomous IPV (Figure 2.32).

Figure 2.32 Colas autonomous IPV in action (reprinted from Colas, 2017)

The autonomous IPV possesses a 'Leader/Follower' capability allowing it to follow a driven 'Leader' vehicle. The Leader vehicle transmits navigation data, including vehicle speed and direction of travel to the 'Follower' vehicle, which uses this to follow the exact path and speed of the leader vehicle all along the route. This removes a person from the part of the operation with the most crash potential.

Another similar development out of Virginia Tech is described to a high level of technical detail in White et al. (2021).

2.10.7 Working at off-peak times

An obvious method of reducing exposure to traffic-related risk is to work at off-peak times. This often means working at night, when the risk-per-unit traffic flow is higher than during the day. However, the lower traffic volumes at night more than outweigh this risk, leading to a situation where the collective risk is generally lower. Section 2.5 discusses methods to reduce this risk by appropriate use of signage and lighting. To take advantage of this risk reduction, the traffic volumes must in fact be lower. This is always worth checking, just in case the TTM site in question is an outlier with a relatively high traffic volume during the night.

NCHRP (2008) carried out investigations of night-time work and daytime work on US highways. They found that:

- overall, working at night was not significantly riskier for individual motorists travelling through the work zone than working during the day
- the percentage increases in crash risk for work operations involving temporary lane closure were essentially identical whether done during night or day
- night work zone crashes were not necessarily more severe than day crashes at similar work zones
- the lower traffic volumes generally present at night result in a much lower number of crashes occurring for similar work zones over similar periods than during the day.

NCHRP (2008) recommended that roadworks involving temporary lane closures be carried out at night.

2.10.8 Avoidance of ‘ghost sites’

When work is not proceeding, sites should be removed or signed as ‘not operating’ and speed limits amended appropriately. This should improve speed limit observance by drivers when the site is operating and thus reduce worker exposure to risk.

2.10.9 Summary takeaways

The best way to reduce risk is to avoid it. Thus, a key aspect of TTM safety is to avoid exposure to risk as much as possible. This may be done in several ways:

- **Strategically planning roadworks to minimise their impact:** ETSC (2011) makes the point that safety – including worker safety – should be a key consideration at all stages in the life cycle of any road-related works project whether it be long, medium, or short term or mobile.
- **Traffic demand management** can be used to reduce traffic volumes through the TTM site and thus reduce exposure to risk at the site.
- **Accurately informing drivers of site characteristics:** Exposure to risk of workers is reduced if all aspects of the site relevant to driver behaviour as they approach the site are effectively communicated to drivers.
- **Reduction of need to cross live carriageways on foot:** Elimination of the need for workers to cross live motorway carriageways on foot was achieved in the UK by using a ‘temporary traffic management signs simplification technique’, which eliminated 40% of the advance warning signs needed for short-duration roadworks. This eliminated an estimated 46% of all carriageway crossings.
- **Reduction of inappropriate vehicle speeds and speed-related risk is important:** Speed is an important factor in crashes at TTM sites. Speeds and speed limits in the vicinity of TTM should relate to the Safe System speed appropriate for that environment. Where this cannot be achieved by other means (eg, immediate feedback of speed), camera enforcement can be considered. One contributor to inappropriate speed is the existence of ‘ghost sites’, which should be avoided.
- **Digitisation of TTM:** Digitisation of TTM means using sensors on TTM equipment like cones and barriers so that any strike or disturbance can instantaneously be relayed to controllers. This reduces the need for routine inspections, thereby increasing safety and reducing greenhouse gas emissions by reducing travel. It also reduces human error.
- **Working at off-peak times:** An obvious method of reducing exposure to traffic-related risk is to work at off-peak times. This often means working at night, when the risk-per-unit traffic flow is higher than during the day. However, the lower traffic volumes at night more than outweigh this risk, leading to a situation where the collective risk is generally lower. Section 2.5 discusses methods to reduce this risk by appropriate use of signage and lighting.

3 Guidance development

The literature, and particularly the various trial studies, identified that there is considerable variation in just how these studies are evaluated and reported. This chapter details the guidance developed to establish and support a consistent approach to evaluating TTM solutions under a risk-based approach. There are two key parts to this risk evaluation guidance:

1. site evaluation guidance aimed at creating a consistent approach to evaluate and report on TTM case studies (monitoring the success of new and existing setups)
2. a 60-second on-site risk evaluation tool (as a sense check to the site plan, and whether it is safe to proceed).

3.1 Method

The guidance development was informed by the literature review. Initial site evaluation guidance was drafted by the research team, which included site factors, exposure data, and evaluation factors (ie, outcome measures). An accompanying 60-second tool for use on site before starting work to assess setup against the agreed plan was also developed (see section 3.6).

The site evaluation guidance was presented, discussed and refined at an evaluation workshop (see section 3.2) with 10 representatives from the TTM industry. The 60-second tool was presented and shared for feedback.

Workshop outcomes were reviewed and interpreted by the research team to create the site evaluation guidance material (see section 3.4), which was applied to four desktop case studies (see section 3.5 and Appendix A).

The material was then reviewed by eight industry experts in a think tank (see section 3.3). Participants identified further improvements and reviewed the applicability of the case study. Attendees discussed the purpose of the guidance and responded to the question ‘Are we creating meaningful change?’

The 60-second tool was piloted on two real-world sites by a Site Traffic Management Supervisor[7] (STMS) accompanied by a member of the research team. Further unaccompanied on-site evaluations were conducted through sharing of the tool with workshop attendees.

3.2 Workshop

An expert practitioner workshop was held with 10 representatives from the TTM industry (including Waka Kotahi, Higgins, Fulton Hogan, Downer, HEB Construction Ltd and Auckland Transport). The two main functions of this workshop were to:

1. discuss and refine the site evaluation guidance approach: how this might fit with existing processes, and how evaluation and capture of TTM case studies could be improved
2. review and input into a draft site evaluation framework, including refining elements around the context of the site setup, the site factors, exposure factors and site evaluation factors (ie, success factors).

[7] Under the new Waka Kotahi TTM warrant system, Site Traffic Management Supervisor has been changed to Site Traffic Management Specialist.

3.2.1 Guidance approach evaluation

Four questions were posed to the workshop attendees. Discussion responses are summarised below, and the full post-it board discussions are in Appendix C.

How well does this fit with your existing process?

The following themes emerged:

- Currently there is no entry point or process around evaluation, so the guidance is filling a gap.
- Clarity of purpose is required for this [guidance] to fit with the existing process, including the end outcome of monitoring.
- The guidance process will be evidence led rather than the current solution led approach.
- The guidance provides pathways for meaningful knowledge sharing and uptake.

What would support better monitoring?

The following themes emerged:

- understanding why incidents are occurring and under what conditions
- understanding uptake pathways for the case studies, where the information provided is going and what happens to the data and insights
- assigning responsibility for ownership of the data
- enabling proactive communication and sharing of case studies, including success stories.

What are the barriers to monitoring right now?

The following themes emerged:

- A culture of compliance means that the existing processes are perceived as inflexible (and therefore hard to trial new options).
- Cost and time to invest in doing this, including the change process, are barriers.
- People need motivation or incentives to do this. The current funding is focused on delivery and not learning/monitoring.
- There is no process to support robust monitoring (with clear, reproducible data).

What is the value of monitoring?

The following themes emerged:

- confidence that we are improving safety
- clear, measurable outputs that can be used to demonstrate safer practice
- promotes a culture of learning and thinking differently
- evaluating safety improvements across all our work (ie, simple to complex evaluations).

3.2.2 Evaluation framework improvements

A range of factors were raised during the workshop, but there were a few important considerations.

Who is filling this out?

There is an expectation that the TTM planner can populate the details and identify an evaluation lead (if not themselves). For the more detailed component it is expected that the evaluation lead would be on site. Someone will be assigned who is responsible for leading the evaluation.

Filtering of information

There was a desire to customise or filter the information required to make this process easier on the user.

Understanding of why specific metrics were useful to capture

Attendees suggested having added information available (like a pop-up box) to explain why this data may be useful for different site problems (eg, barrier or cone hits may indicate the setup is not well understood by the public, the path is too tight for large vehicles, or vehicles are travelling too fast).

Additional measures

Additional measures that were included in the site evaluation tool based on the workshop feedback were:

- type of work activity being undertaken (eg, cyclical maintenance, new construction like a roundabout), as this can have different impacts on the type of risk at site (based on different machinery and heavy vehicles required)
- whether it was a specifically designed plan (as opposed to pre-approved plan)
- unintended consequences (have any new risks been caused by this setup?)
- dangerous manoeuvres (late stopping / overtaking breaches)
- attenuator truck strikes
- cone hits or barrier hits
- road user aggression.

An on-site overall insights question was also added so that the evaluation lead who has experienced the trial first-hand should has the opportunity to capture their insights around success and the use case for this type of setup (if any; see section 3.4.5).

Other factors that came up in relation to relevant site factors that could be considered, but were not explicitly included as their own categories, include:

- work site access and egress
- upstream and downstream conditions
- detour routes (any flow-on impacts to safety due to added traffic)
- percentage of heavy vehicles
- urban/rural
- land use
- One Network Framework
- hourly traffic flow.

3.3 Think tank

The think tank was attended by eight industry experts. It captured higher-level inputs into TTM evaluation governance, funding, monitoring, and shifting to a learning culture. The group also reviewed the use case for the 60-second tool. Finally, there was a discussion looking at why there was a lack of existing case study evidence and how this could change. Outcomes and discussion points are captured in section 6.3.

3.4 Site evaluation guidance

The purpose of this co-designed guidance is to make it easier to perform site safety evaluations by providing a consistent, practical approach to evaluating and reporting on new and existing TTM setup solutions.

The outcome through the final step of the guidance is to provide a framework of success metrics that allow for differences in context to capture these TTM setups as case studies. Groups of case studies can then form technical advice notes to improve safety and provide a pathway to standardise success and learn from failure.

The work described above in sections 3.1 to 3.3 has produced the following 5-step guide:

1. **Problem:** What is the problem we are trying to solve?
2. **Evidence:** What is the evidence of the problem?
3. **Options and solution:** What options have we considered? Why do we think the selected option will work?
4. **Describe the site:** What core factors do we need to know about?
5. **Evaluation:** How will we evaluate the success of the trial?

Each of these questions is expanded on below.

3.4.1 What is the problem you are trying to solve?

1. What is the nature of the problem that the new TTM method is hoping to overcome (eg, vehicles speed through a work site; see Figure 3.1)?
2. Explain why this problem needs solving. For example, higher speed will increase the likelihood of an incident, errant vehicles pose a threat to road workers, and the higher speed will increase severity of outcomes should an incident occur.

Figure 3.1 Defining the nature of the problem

Examples of problems to consider / What sorts of problems have you encountered?

- **Exposure:** High traffic flow, TTM setup has many lane crossings, multiple staff required, long setup times
- **Road user errors**: Travelling too fast, inattention, late lane change, failure to follow instruction from traffic controller, breach of the work area
- **Worker errors:** Driver error (eg, while reversing), worker distracted, moving into unsafe workspace, moving across live lane when traffic present, incorrect PPE, incorrect site setup
- **Site setup and conditions:** Is the problem particular to mobile sites, speed zones, land uses, curvy roads, or certain environmental conditions like night or high rainfall sites?

3.4.2 What is the evidence of the problem?

Examples of evidence

It is important that any trial is led by an existing problem (as opposed to a solution trying to find a problem). State the evidence that this problem exists. Note that evidence could be measured objectively, observed, or perceived. Expert perceptions are a valid indicator of something not working correctly at the site.

- **Observed:** via near miss, audit data, or observations of cone or barrier hits
- **Perceived:** staff members raised concerns or even quantified perceptions of safety (ie, scale of 1 to 10 across site staff)
- **Measured:** via monitoring equipment (like speed monitoring)

3.4.3 What are the options for solving this problem?

Identify the range of TTM options that could potentially solve the problem.

- Provide a short description of each option explaining how it might solve the problem, and any disadvantages.
- Briefly describe the preferred option and why it might work.

It is important that each option considers the hierarchy of controls to demonstrate that the highest level of practicable solution is selected.

3.4.4 What are the core site factors?

Describe the relevant site factors and provide supplementary detailed drawings and photographs of site setup where appropriate. Use the examples in the Table 3.1 below to describe the site.

Table 3.1 Identification of relevant site factors

Site factors
• **Speed limits:** fixed speed zone • **TSL speed on road** (km/h) • **Number of lanes** • **Number of intersections or on/off-ramps** • **Type of TTM being done:** mobile; static; semi-static • **Specifically designed plan** (ie, not pre-approved) • **Type of work being done:** eg, cyclical maintenance; repairs; new intersection • **Time of day that TTM will be active:** peak; off-peak; day; night • **Road users:** pedestrians; cyclists; cars; buses; heavy goods vehicles • **Adjacent land use** • **AADT**

3.4.5 How will we evaluate the success of the trial?

Identify the data to be collected before and/or during the TTM trial. The following types of data could be collected for evaluating the TTM site.

- Select exposure (Table 3.2) and evaluation (Table 3.3) measures based on the issue you are trying to solve and the change you are trying to make.
  Note: If you are not altering exposure, you do not need to collect this.

Table 3.2 Examples of exposure data that can be collected

Exposure data	
Does your case study change exposure (eg, fewer people/less time on site/less traffic)? If no, skip this table.	
People	• Number of TTM workers during setup/breakdown • Number of TTM workers during work activity • Number of non-TTM workers on site
Site	• Traffic flow while on site (cars; heavy goods vehicles; buses; motorbikes; bikes; pedestrians; scooters) • Clearance between traffic lane and workers (in metres) • Type of barriers/protection • Duration of active work (hours with staff on site): TTM/other staff • Duration of hours for TTM setup • When is site unattended (number of hours; which hours)? • Number of times of TTM setup/breakdown (per day/week/month)

Table 3.3 Examples of evaluation data that can be collected

Evaluation data	
Speed	Traffic speeds
Exposure	Exposure reduction (hours / people / traffic)
Safety observations	• Workers self-reported near misses • Dangerous manoeuvres (overtaking / late stopping / breach) • Vehicle hits • Cone or barrier hits • Road user aggression (verbal and physical assaults) • Unintended consequences – any risks that have been caused by this setup
Subjective assessment	• Road user comprehension • Workers' perceptions of safety • Potential unintended consequences
Automated data	• Camera AI (artificial intelligence) (eg, serious near miss)

On-site overall insights

The person involved in leading the trial and who has experienced the trial first-hand should also capture their insights, which could include the following open-ended prompts:

- Do you think we should continue with this type of approach?
- Did the results match up with what you experienced on site? If not, what was different?
- What were the main advantages and disadvantages of this TTM approach?
- Do you have any other insights from this trial that could be used to improve TTM sites in the future?

3.4.6 Trial checklist and details to consider

Finally, the more detailed elements to consider when conducting the trial concern how the trial will take place:

- Planned set up and layout for the trial (equipment) and the roles of the workers.
- Identify the time frame for the trial.
- Early-stage monitoring of trial: Are back-up safety systems required and how would these be used?
- When will the assessments be undertaken (eg, speed measurement 24 h/day for 1 week; road user surveys once a day; worker surveys at the end of the trial)? Will data be collected before the TTM equipment is set up?
- How will the data be collected and analysed (eg, iPad, paper-based questionnaire, CCTV)?
- Who will collect and analyse the data?

Complete the evaluation checklist below:

☐ The problem is well defined.

☐ A selection of TTM options have been identified and assessed for suitability.

☐ The views of the stakeholders (ie, road users and workers) have been considered.

☐ The trial is based on sound scientific design that enables robust statistical analysis so that conclusions can be reached.

☐ Assessment measures are appropriate.

☐ There is a realistic period for the assessment.

☐ The suitability of any site suggested for the evaluation has been considered.

☐ There is inclusion of close monitoring of the trial, especially in the early stages of field implementation.

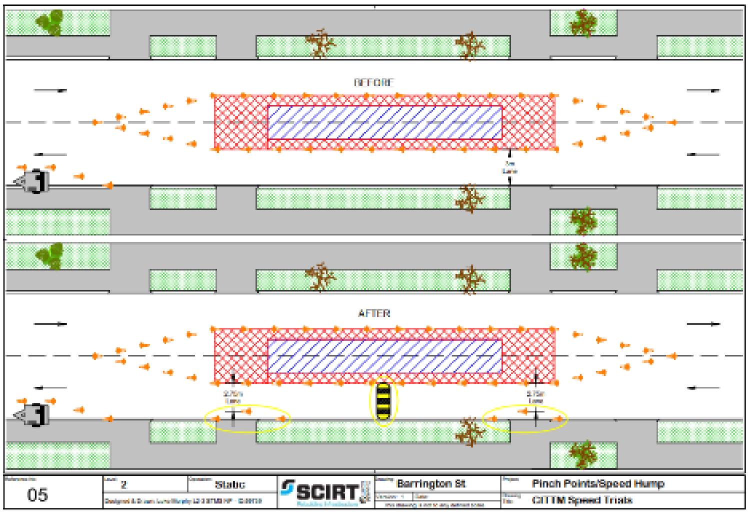
☐ There is sufficient information to determine whether value for money will be achieved if the proposal is implemented nationally.

3.5 Example case study

An example case study is listed below. For other examples see Appendix A.

Case study	**Stronger Christchurch Infrastructure Rebuild Team Speed Treatment 5**
Road name / GPS location	Barrington Street, Christchurch
Problem statement	Speed coming into urban work zone
Evidence of problem	Perceptions of road workers and concerns for safety; measured speeds
Options considered	Removal of temporary speed limits (TSLs); lane narrowing; speed humps; speed feedback message boards
Option selected	Speed humps and lane narrowing (from 3 m to 2.75 m)

Site factors	**Fixed speed zone**	50 km/h
	TSL speed on road (list)	30 km/h
	Number of lanes	2
	Type of TTM being done	Static
	Type of work being done	Unknown
	Time of day (select all that apply)	Y Peak Y Off-peak Y Day N Night
	Road users	Y Walking Y Cycling Y Bus Y Heavy goods vehicle
	Adjacent land use	–
	AADT	16,000
	Duration of work (days)	2
Evaluation factors	Traffic speeds	Y
Evaluation finding	Traffic speed	4.6 km/h 85th percentile speed reduction
Attachments	Site photos and/or site diagrams available	Y



3.6 60-second tool

The purpose of the 60-second tool is to test whether the site plan will work once at site and whether any new on-site information about the setup or conditions may alter the risk profile. In particular:

- What assumptions were made about the site (ie, that may have underestimated the risk)?
- Are there other site factors that have not been considered?
- Can we adapt to manage these factors or does the site need to be re-planned?

The tool provides an efficient checklist (ie, it could be filled in within 60 seconds once familiar with the format) that supports the STMS to consider a wide range of risks. See Appendix D for the checklist questions.

3.6.1 Philosophy behind the tool

The tool was designed with the assumption that an STMS is a competent practitioner that will make appropriate decisions when risks are brought to their attention. Therefore, it is about raising awareness of the wider range of risks on site, such that staff can make better decisions around site safety as opposed to a more prescriptive approach that provides criteria for a threshold at which the site can no longer be operated.

3.6.2 When to use the tool

The intention is that this tool will be used upon arrival at site (ie, done before initial setup). An STMS can determine whether anything has changed, or new information is available that may alter the risk profile (ie, they could re-run it after the site is set up, at each shift change, daily, or at a noticeable change in conditions such as the type of work being done, traffic, lighting, or weather).

3.6.3 How will the tool be delivered?

The tool has been developed for easy delivery via either a paper-based checklist or via a device (ie, mobile phone or tablet).[8] The proposed process is to go through a checklist of common areas where site-based evaluation can validate the office-based plan.

3.6.4 What factors were considered?

The criteria for inclusion were those factors that had the potential to have unexpected variation from the plan. Factors were derived from best practice in British Columbia and Western Australia (see section 2.6.3) and refined and added to, based on review of existing New Zealand tools and expert opinion. The following refined list of 12 items was developed:

1. Vehicle speeds (as expected or lower)
2. Vehicle volume or flow (consider queues)
3. Number of pedestrians or cyclists (consider nearby schools or bike lanes)
4. Curves in the road or slope (consider viewing distance and ability for trucks or cars to stop safely)
5. Available space (eg, roadside features/signs causing blockage to any user path: car, truck, cyclist, pedestrian)
6. Road conditions (eg, worn or ghost line markings, or poor skid resistance)
7. Weather conditions (eg, reduced visibility and ability for trucks or cars to stop safely)

[8] Note: For the purposes of this study we trialed this as an online Survey Monkey link and printable PDF so that users could test it.

8. Light conditions (eg, twilight, or shift from day to night conditions)
9. Visibility of safety devices (ie, visibility of existing or temporary signs or markings)
10. Staff/equipment (consider numbers or condition of staff (eg, fatigue) or equipment (eg, damaged/non-reflective signs))
11. Physical separation between workers and road traffic (consider both distance to live traffic and use of barriers)
12. Other nearby work sites (within about 3 km that could impact your site)

This list of factors was then pilot tested for improvements (see sections 3.6.6 and 3.6.7).

3.6.5 Benefits of the tool

Identified benefits of the 60-second tool include:

- enabling consistent, efficient, field-led risk-based assessment
- enabling field staff to legitimately assess and apply safety changes
- providing better data for planners and road controlling authorities (RCAs) around field insights
- providing better data for auditors to support positive change
- enabling knowledge sharing and support around safety changes.

See section 6.3.3 for a discussion of the usefulness of this tool.

3.6.6 Supervised pilot test

The tool was trialled on site by STMSs that were accompanied by a project team member to observe how the tool would be applied in a real-world environment.

3.6.6.1 Site details

Two semi-static temporary management sites were visited – one in the evening at about 19:00 and one in the morning at about 09:30. Both sites were visited during the work week and required a semi-static closure of a single lane.

The evening site was located on State Highway 2, between Tawa and Churton Park, in the south bound lane. The work being carried out was a geo-tech inspection of the embankment running along the side of the state highway.

The morning site was located on State Highway 1, outside the ASB Sports Centre, Wellington, in the northbound lane. The work being carried out was drilling of holes for the installation of pedestrian crossing infrastructure and signals.

3.6.6.2 STMS details

A different STMS attended each site. Both had been with their company for approximately three years and had held their Level 2/3 STMS warrants for the same period of time (ie, three years).

3.6.6.3 State Highway 2 site (evening site)

The tailgate meeting,[9] including the contractor briefing, took place at the Porirua railway station, where the STMS had identified an issue with a greater number of contractor staff and vehicles than originally planned.

[9] A tailgate meeting is the last point of discussion before commencing work on site.

There was also a change in the proposed method in which the work was to be conducted, with in-vehicle inspections being replaced with on-foot inspections from the carriageway shoulder.

Mitigations for both issues were discussed, and the tailgate and mitigation measures were agreed by all staff before proceeding to site.

Once on site the STMS ran through the tool indicating that everything was as expected at site apart from deviations in the following two categories:

- Staff/Equipment
- Physical separation between workers and traffic.

The ‘Staff/Equipment’ issue was in relation to more staff being on site than originally proposed and the ‘Physical separation between workers and traffic’ issue was due to a greater number of contractor vehicles being in front of the lead attenuator than originally planned. As stated above, both issues had mitigations in place as decided before arriving on site.

3.6.6.4 State Highway 1 site

The site briefing took place in the site office located in the ASB Sports Centre carpark. Potential issues with the drilling equipment being able to access the desired drill locations were raised and mitigations were discussed (see Figure 3.2 for an image of the site).

Once on site the STMS completed the 60-second tool, noting there were no deviations from the proposed TTM plan (at that time). Once the site was established, the drill equipment issue did cause intrusion into the pedestrian pathway and mitigations were applied.

Figure 3.2 State Highway 1 work site and attenuator (captured during evaluation)

3.6.6.5 Observations on use of the tool

Both STMSs found the tool quick to use and stated the questions were like those that had to be answered as part of their internal compulsory traffic management plan site checklist. One of them stated they also liked the acknowledgement within the tool that they were ‘helping everyone get home safe’.

One of the STMSs stated they had to read the questions twice to understand what was being asked, therefore it is recommend that the wording of the tool be extensively tested for comprehension and readability before being deployed.

Both noted that the tool was quicker to use than the company-supplied tool, which asked similar questions, and saw the benefit of the 60-second tool for those that didn’t have something similar already in place.

3.6.6.6 Potential improvements

Both STMSs identified potential ways in which the tool could be altered or improved:

- One suggestion was for the tool to give feedback on overall site safety based on the responses given so the STMS receives an extra prompt to ensure they are making sure their site is as safe as possible.
- Another suggestion was breaking out the ‘Staff/Equipment’ question into two separate questions. So, one question would be in relation to the perceived fitness of staff on site to carry out the prescribed work (ie, are staff fatigued etc) and the other question would specifically be in relation to equipment issues.

3.6.7 Unsupervised pilot test

Along with having the tool tested by STMSs while accompanied by a member of the project team, it was also distributed to the project steering group, workshops and think tank attendees and tested by STMSs without being observed by the project team. This method allowed the tool to be used more naturalistically but did have the disadvantage of limiting the feedback on the tool to self-reported use and potential improvements.

3.6.7.1 Self-reported observations on use of the tool

Users of the tool thought that it would be a good method for helping the STMS think about potential site issues before site setup.

3.6.7.2 Potential improvements

One of the suggested improvements was that the tool be used not just for site setup but also whenever there was a change to the site or changes in the types of road users (eg, suddenly lots of cyclists), or the tool be used periodically throughout the site deployment. Having the tool used at regular intervals would capture site changes that may not have been present at site establishment.

The rest of the suggested improvements related to adding questions such as:

- presence of:
  - driveways
  - side roads
  - fixed signage
  - level crossings
  - intersections
  - traffic lights
  - bus stops
  - parked cars
- appropriate road width for site layout.

4 Interviews

A series of 11 semi-structed interviews were conducted as the first step in developing a TTM worker perceptions, attitudes and behaviours survey to inform the survey questions. Interviewees were those who are part of the TTM process. Roles included:

- road controlling authority (RCA)
- traffic management controller
- roading contractor
- TTM planner
- site traffic management supervisor (STMS)
- auditor.

Interviewees were selected from various locations and organisations from around New Zealand. Due to the interviewees supplying their answers under anonymity, the exact organisations cannot be reported.

All interviewees were asked about:

1. roles and responsibilities in relation to TTM
2. information regarding near misses and incidents
3. key risks in relation to TTM and understanding of the risk-based approach and its hierarchy of controls.

The STMSs were also asked a supplementary question in relation to their comfort in challenging issues with TMPs once on site. A full list questions is in Appendix B.

4.1 Roles and responsibilities

The range of experience in TTM interviewees was from six months to over 20 years. Those interviewees that had multiple years' experience had also generally held various positions within the TTM process.

All interviewees stated that in their current role they had some form of responsibility for safety in relation to TTM. This responsibility for safety also covered all those who interacted with TTM (eg, TTM workers, contractors in the working space, pedestrians, and other road users).

When asked who the interviewee 'mainly' worked with to manage site safety, the responses were not purely focused on internal roles. External parties and stakeholders were mentioned by many interviewees as either directly being consulted with or were actively considered when it came to TTM safety.

4.2 Near misses and incidents

When asked about the number of incidents at TTM sites, there was a strong consensus across the interviewees that these were very few and far between. Most interviewees could not readily recall a reported incident on the sites they were involved with or an incident in the time they had been in their current role.

Given the very low level of reported incidents, the rest of the questions focused instead on near misses at TTM sites.

All interviewees stated there were multiple near misses at the TTM sites they were involved with, and that most of these near misses went unreported.

The types of near misses that occurred were generally attributed to other road users, and these near misses were happening due to inattention or confusing/poor site layouts. For example:

- drivers failing to see manual traffic controller with stop/go sign and driving into oncoming traffic
- pedestrians failing to follow detours and walking through site
- excessive braking by drivers as they failed to see traffic queue
- failure to comply with TSLs.

Most interviewees also reported that near misses were being caused by road worker behaviour – for example, walking in the live lane and workers not paying due care and attention to plant (diggers, rollers, etc) moving on site.

In relation to reporting near misses, all interviewees said their organisations had digital methods for capturing near misses such as an app. In some instances where near misses were captured on paper, these were then input into the organisation's digital systems later. The data collected with these near miss systems followed a similar pattern for all interviewees (eg, time and location, description of the event, who was present).

When asked why near misses were not being reported, various responses were given, including:

- It happens so often it is just seen as part of the job.
- Given the frequency of near misses there would need to be a dedicated person on site whose only job was to report them.
- If too many near misses are reported it might give the impression the site is unsafe, so either everyone needs to report them or no one reports them for fear of standing out.

4.3 Key risks and the risk-based approach

Most interviewees stated that the greatest risk in relation to TTM was when the site was being set up. The main reason for this was that other road users are not aware that they are approaching roadworks as advance warning was not yet in place.

Measures for mitigating this risk varied depending on where the interviewee sat in the TTM process – that is, an RCA's ability to impact on TTM deployment was different to that of an STMS. Some of the mitigation measures raised were:

- processes to reduce deployment time and breaking deployment into manageable sections
- tailgate/toolbox meetings
- auditing the deployment process
- balancing the use of mobile vs static sites
- making sure the TMP is right first time and covers all road users and potential risks and challenging it where it may be wrong
- making sure the STMS is fully aware of the site environment and safety risks
- ensuring all staff are suitably qualified to carry out the proposed work.

The majority of interviewees were aware of the risk-based approach and its hierarchy of controls to varying degrees, with those more orientated to the planning and administrative side of TTM (eg, traffic management controllers, TTM planners, and road contractors) having a greater understanding than those at the more applied end of the spectrum. A similar pattern of responses emerged when interviewees were asked if they were already applying the risk-based approach in their current roles.

In relation to the hierarchy of controls and its implementation within TTM, there was a general consensus among those that were familiar with the controls and were currently using the risk-based approach that while ‘elimination’ was recognised as the ideal mitigation method, it was minimisation that was being used more.

This bypassing of ‘elimination’, which in the sense of TTM generally means full carriageway closures, was seen to be in response to a period where the default mitigation method was a closure without detailed explanations to the RCAs as to why a closure was required. This lack of information led to TMPs being declined, which in turn meant a move away from ‘elimination’ to more ‘minimisation’ approaches.

The RCAs interviewed stated they did not have an issue with a request for carriageway closures in and of themselves – rather, they required more information than they were receiving in the original applications to justify the closure.

Overall, interviewees thought the hierarchy of controls, where implemented, was being done well even if ‘elimination’ was not the first go-to step.

When asked what benefits the risk-based approach brought to the TTM process, an improvement in safety was mentioned by every interviewee. Other benefits stated by the interviewees were:

- it would result in efficiencies in time and costs
- it would facilitate thinking outside the box (ie, outside the confines of the Code of Practice for Temporary Traffic Management) and offer greater flexibility, which leads to more options
- it would help those involved in the TTM process to move away from the bottom-up approach of PPE first (for those that are currently of this mindset)
- it should bring more people into the process, meaning more ideas are in the mix.

In relation to the challenges interviewees thought would arise when trying to implement a risk-based approach across the entire industry, two common responses came through:

1. There will potentially be issues with differences in perceived levels of risk and levels of risk tolerance. For example, a highly risk-averse STMS is going to have different site layout preferences to an STMS who is less risk-averse.
2. For some, this is a complete change of thinking and requires changing how they approach implementing TTM sites. For example, those who work in a bottom-up fashion in relation to the hierarchy of controls have to completely flip their approach, which may be going against years of incident-free TTM implementations.

The final question of the interview was specifically for the STMS interviewees and related to how comfortable they felt in changing an approved TMP to address a newly identified risk. The interviewees who were practising STMSs said they felt entirely comfortable raising issues with the TMP and had full organisational backing in changing TMPs on safety grounds. One of the interviewees highlighted that this ability to challenge the TMP was also extended to other staff on site, such as traffic controllers.

5 Attitudes and behaviours survey

A survey was constructed with the intent of creating a baseline of workers' attitudes, behaviours (including near misses) and perceptions surrounding planning and managing risk at all levels of the TTM industry using a risk-based approach. The survey was designed so that it could be used repeatedly and allow for comparisons to be made over time (see Appendix E).

5.1 Method

5.1.1 Participants

Participants were 316 workers with various roles, locations and experience. Convenience sampling was used to distribute an online survey via multiple channels, including personal communications, the Waka Kotahi critical risk team, and the TTM industry newsletter. It was important that a range of participants throughout the industry participated to understand the attitudes, behaviours and perceptions throughout the industry. Regular checks were completed on the role types of the participants to ensure there was diversity in respondents' roles, and paper versions of the survey were made available to on-site workers to improve ease of participation where possible.

The majority of respondents (60.04%) had been working in the industry for more than five years (Figure 5.1) and indicated that they worked on site regularly (70.9%) (Figure 5.2).

Figure 5.1 Years of experience working in the TTM industry (*n* = 316)

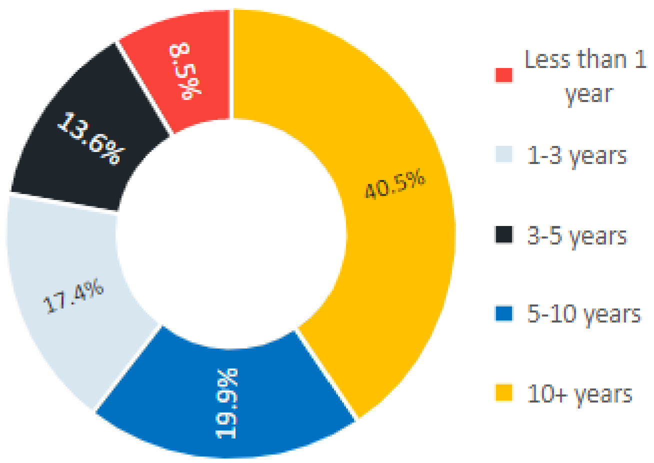
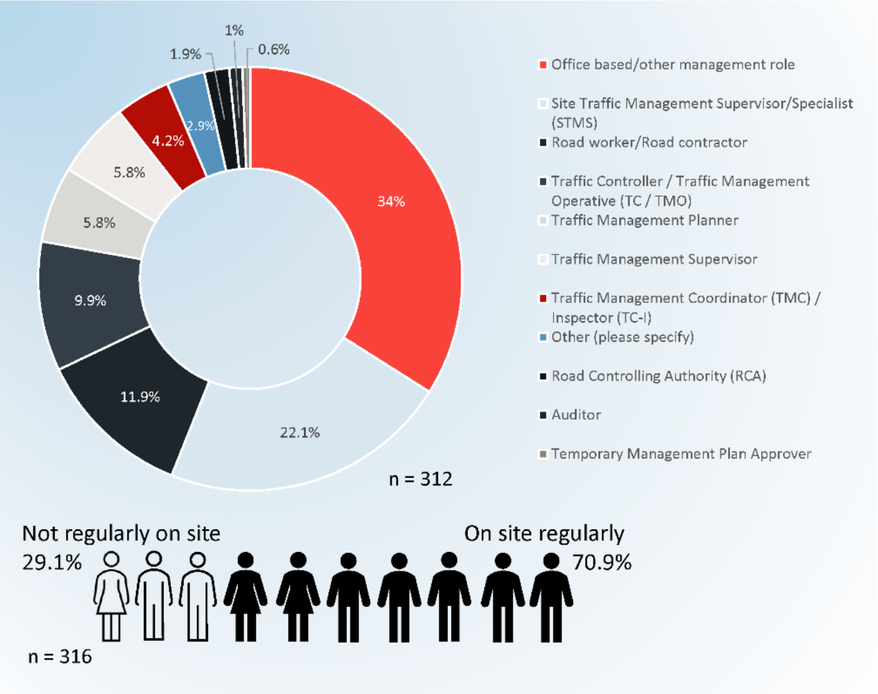


Figure 5.2 Breakdown of participant roles and regularity on site

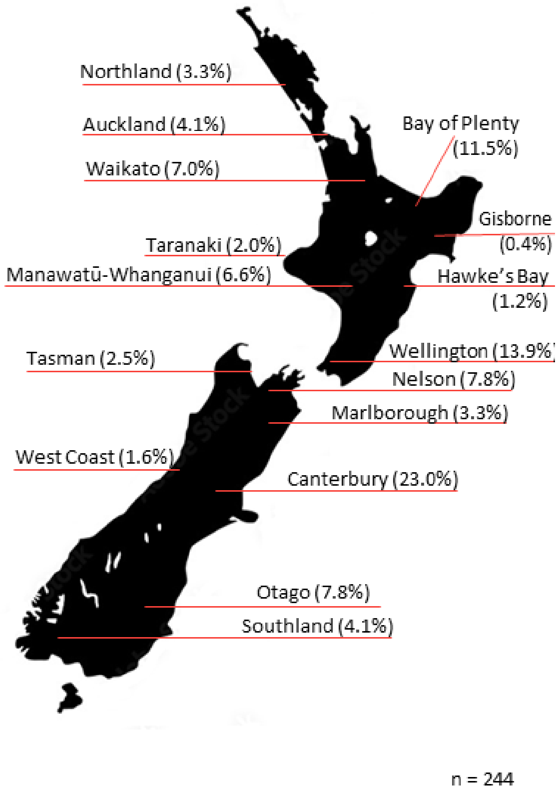


Of the 236 respondents who disclosed their age, half of the sample reported that they were between the ages of 20 and 40 years old (Figure 5.3). Of the 204 participants who disclosed their gender, the majority were male (71.6%).

Figure 5.3 Age of participants

Respondents' reported locations show high uptake of survey completion in the Canterbury, Bay of Plenty, and Wellington regions. While Auckland is a large region, the proportion of respondents was low (4.1%) (see Figure 5.4). This demonstrates one limitation of the convenience sampling approach (see section 6.6).

Figure 5.4 Location of participants throughout New Zealand



5.1.2 Survey design

The survey examined three main areas:

1. Safety culture
2. Risk-based approach
3. Last complex site

5.1.2.1 Safety culture

Respondents' perceptions of safety under different site conditions were examined (including sporting/event sites and sites without barriers). Respondents answered questions related to safety trade-offs (eg, traffic flow or cost being prioritised over safety) and empowerment to communicate unsafe conditions or developing safety concerns. Attitudes towards near-miss events on sites were also reported.

5.1.2.2 Risk-based approach

To comprehend workers' understanding of the risk-based approach, respondents were asked to rank each of the risk-based controls on their order of effectiveness.

This section examined acceptance or willingness to adopt the risk-based approach (actively and encouraging others; approving of the approach; approving of the approach but find it difficult at times; or solely find the approach difficult).

Respondents were also asked to rank the controls based on their effectiveness at reducing risk, in addition to ranking their confidence in understanding a risk-based approach on a 10-point scale.

5.1.2.3 Last complex site

For the purposes of this survey, a complex site was defined as ‘a site where something at the location made you consider the risks more than usual (such as limited space or view, or different traffic conditions)’. The complex site conditions section included:

- frequency of applying the risk-based approach on site (eg, use of PPE, engineering controls used to reduce speed).
- detailing a recent serious near miss (where on site it occurred and who was at most at risk of injury).

For the purposes of this survey, serious near misses were defined as ‘near misses that have the potential to result in serious injury or fatality’.

Respondents were asked to report the frequency of near misses on the last complex site that they worked on. The following note was added to the survey: ‘Near misses are unplanned events that did not result in injury or damage but had the potential to do so. For example, where a worker trips over but does not suffer an injury.’ This section included:

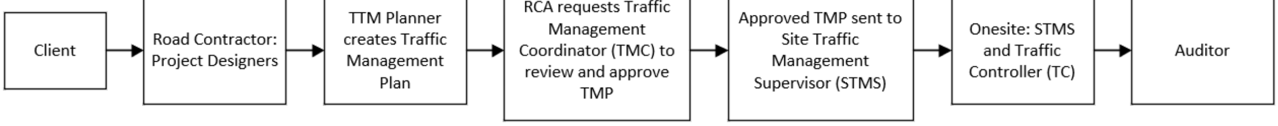
- perceptions of the frequency in which risk reduction methods are used (eg, elimination, use of PPE).
- contributing factors to near-miss incidents.

Site analysis was also completed on questions related to perceptions of site behaviour related to both workers and public drivers, including:

- estimations of on-site near misses for the last complex site worked on
- near-miss location (advance warning zone, direction and protection zone, closure zone, end of work zone).

Information was collected on workers’ current role/position, their frequency on work sites, and the length of time they have been working in the TTM industry. Demographic information was also collected, including age, gender, ethnicity and the location they work from. The survey aimed to cover the roles involved in creation, implementation and auditing of TTM (see Figure 5.5).

Figure 5.5 Roles within the TTM process



The survey content was informed by the literature review and interviews. Additionally, questions related to culture and reporting, and risk-perception and safety from other industries were used to help inform the organisational culture section of the survey. The questions about the organisational and sector culture were developed with reference to questionnaire items from Eurocontrol (related to an aviation environment) with items adapted from the culture and reporting section and communication and learning section of the survey

(Shorrock et al., 2011). Further adaptations were made with reference to a risk perception and safety survey used in the oil and gas industry (Flin et al., 1996).

An easily understood definition of near miss was derived from the National Safety Council (2013), and types of near misses were derived from findings by Debnath et al. (2013, 2015).

Additionally, the survey was structured where possible to reflect through the work events and included question on:

1. Planning phase
2. Set-up of site
3. TTM activity
4. Breakdown of site
5. Return trip.

Due to the length of the survey and the nature of the working environment, a split survey method was implemented (see also Appendix F). This ensured the length of the survey was acceptable for respondents to complete, which was a particular concern for workers who were not office-based. For those who indicated they were on site, random allocation was used to give one of two possible branches in the survey – one related to the complex site, the second to the questions on safety culture of TTM. Those who indicated they were not on site regularly were presented survey questions related to safety culture to complete. This was to ensure that workers who were office-based did not receive questions related to site conditions and near misses.

There were several benefits of our approach, including:

- the reduced time of the survey encouraged participant uptake and reduced the likelihood of survey fatigue
- it allowed for a broader range of questions to be answered without increasing the length of the survey.

5.1.3 Analysis

Data analysis consisted of descriptive statistics. Independent *t*-tests were conducted to determine if there were differences between gender and site regularity. Results have been reported only where significant differences were found.

5.2 Results

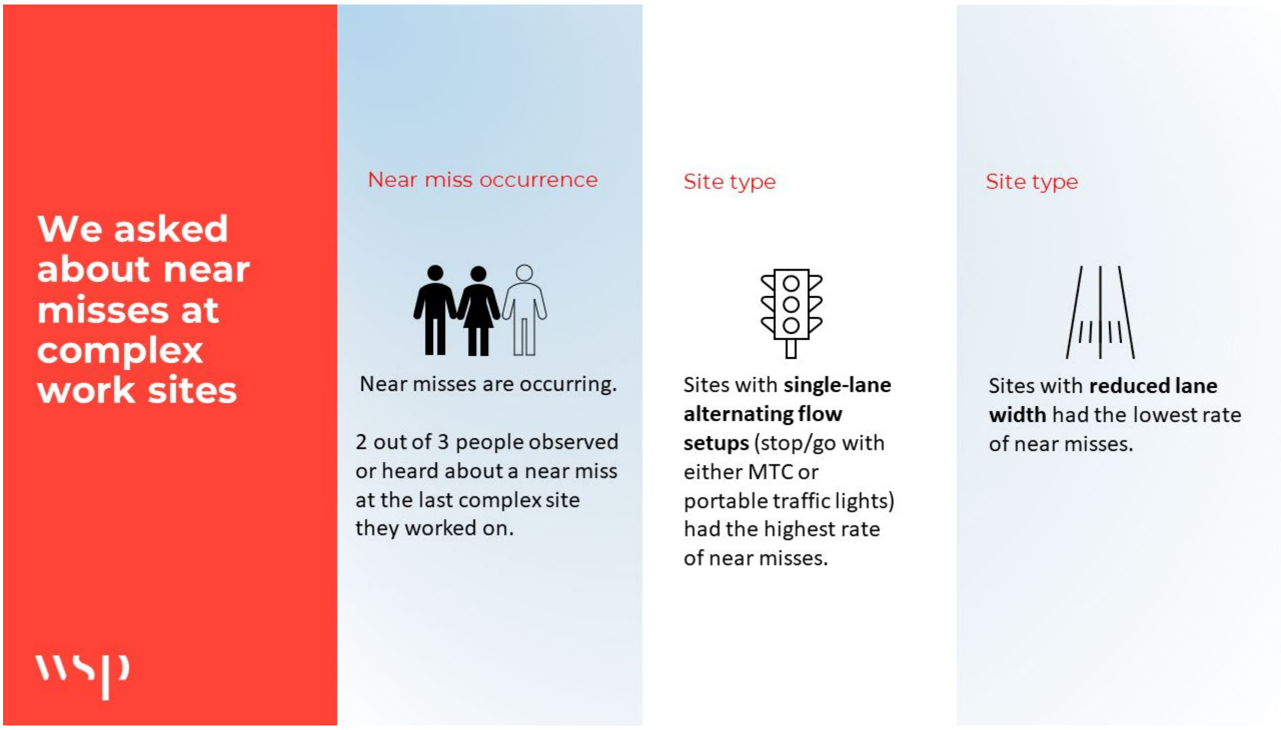
The key results have been delivered in a PowerPoint format to enable wider sharing of the findings. See Appendix G for a copy of this report. A summary of results is provided in Figures 5.6 to 5.9 below.

Figure 5.6 Summary of responses to safety culture

Figure 5.7 Summary of responses to the risk-based approach to TTM

Figure 5.8 Summary of responses to complex site details

Figure 5.9 Summary of results for near misses at complex sites



Note: MTC = manual traffic controller

5.3 Limitations

Limitations of the survey are discussed with all research limitations in section 6.6.

5.4 Consistency with other data sources

To check for consistency in reporting, a comparison was made between the serious near miss survey results and the Waka Kotahi audit programme dashboard data (supplied via Ryan Zheng, Asset Information Specialist, Activity & Design, Wellington Transport Alliance, personal communication, 16 September 2022). The consistency review was conducted through the following steps:

1. Review of survey site types and associated audit programme dashboard site types to identify commonalities (Table 5.1).

   Four items on the audit programme dashboard (TSL, lane shift, footpath closure, nothing) could not be matched with the survey site types. Data associated with these site types was not included in the comparison.

Table 5.1 Comparison of survey site types and audit programme site classifications

Survey site types	Audit programme site classifications
Single-lane alternating flow	Stop/go
	Temporary signals
	Contraflow
Reduced lane width	Shoulder closure
No lane closures	Warning only
	Inspection
Full closure	Road closure
Lane closure	Lane closure
	Mobile closure
Non-match	*TSL*
	Lane shift
	Footpath closure
	Nothing

2. Comparison between survey proportion of sites with near misses and audit programme dashboard percentage of sites in each site type identified as unacceptable or dangerous (see Table 5.2).

   These classifications were combined and represent unacceptability either through the auditor's weighting methodology based on compliance of worksite setup, staff (eg, qualified person on site) or paperwork (eg, missing an approved TMP or completed TSL matrix).

Table 5.2 Comparison between proportion of sites with near misses and audit programme percentages of unacceptable/dangerous

<table>
<tr><th>Survey site types</th><th>Audit programme site classifications</th><th colspan="2">Audit programme unacceptable / dangerous</th><th>Audit total</th><th>Audit % unacceptable + dangerous</th><th>Audit % total unacceptable + dangerous</th><th>Survey proportion of sites with near misses</th></tr>
<tr><td rowspan="3">Lane closure</td><td>Lane closure</td><td>1</td><td>0</td><td>1</td><td>100%</td><td rowspan="3">71%</td><td rowspan="3">77%</td></tr>
<tr><td>Mobile closure</td><td>1</td><td>6</td><td>10</td><td>70%</td></tr>
<tr><td>Contraflow</td><td>2</td><td>0</td><td>3</td><td>67%</td></tr>
<tr><td rowspan="2">Single-lane alternating flow</td><td>Stop/go</td><td>7</td><td>6</td><td>22</td><td>59%</td><td rowspan="2">5%</td><td rowspan="2">67%</td></tr>
<tr><td>Temporary signals</td><td>4</td><td>0</td><td>9</td><td>44%</td></tr>
<tr><td>Reduced lane width</td><td>Shoulder closure</td><td>8</td><td>5</td><td>21</td><td>62%</td><td>62%</td><td>50%</td></tr>
<tr><td rowspan="2">No lane closures</td><td>Warning only</td><td>0</td><td>1</td><td>5</td><td>20%</td><td rowspan="2">17%</td><td rowspan="2">46%</td></tr>
<tr><td>Inspection</td><td>0</td><td>0</td><td>1</td><td>0%</td></tr>
<tr><td>Full closure</td><td>Road closure</td><td>0</td><td>0</td><td>3</td><td>0%</td><td>0%</td><td>50%</td></tr>
</table>

For three site types there was some level of consistency between the audit data and survey proportion of sites with near misses (single-lane alternating flow, reduced lane width, lane closure); however, there was not a clear pattern of comparison across the audit and survey data. This may be due to:

- limited number of audits in some categories (eg, full closure)
- variation in breadth of audit (eg, ‘no lane closure’ sites require less traffic management to audit for compliance).

For accurate comparisons to be made across the two data sources, consistency is required in site type naming conventions. Further analysis is recommended once more audit data is available.

6 Discussion and conclusions

6.1 Risk-based safety solutions

The best way to reduce risk is to avoid it. Thus, a key aspect of TTM safety is to avoid exposure to risk as much as possible (see section 2 for details beyond those summarised here). Safety, including worker safety, should be a key consideration and costed into all stages of any road-related works project (ETSC, 2011) regardless of the type of work or length of the project. Late inclusion of worker safety limits application of the best risk-reduction tools.

Allowing for TTM as a core component of planning enables implementation of the best safety solutions, which this research identified as:

- **digitisation of TTM** – using sensors and technology to eliminate the need to be on site as much as possible for tasks like inspections
- **traffic demand management** – including road closures or working at off-peak times to reduce risk by reducing exposure to traffic volume.

Work site setups need to be optimised to promote the right behaviour, including:

- **better information to drivers** – following the principles of the four C's (conspicuous, clear, consistent, credible), using appropriate lighting, signage, pavement markings and channelisation
- **reduction of inappropriate vehicle speeds** – including the use of real-time (immediate speed feedback signs) or enforcement-based approaches (ie, speed camera enforcement)
- **reduction of risky worker behaviour** – including setups that minimise higher-risk behaviours like live carriageway crossings on foot by using techniques like sign simplification, which can reduce carriageway crossings by almost half in some instances.

There are also indications that TTM solutions need to be fit-for-purpose for the full range of site conditions, whether it is curvy geometry, narrow sites, poor weather or night work. This should be a focus area for trials. The example of night work safety illustrates this point well – shifting work to off-peak times is a risk-based control.

The survey findings revealed that about two in five workers feel less than 'somewhat safe' at night, which is supported through surveys of Australian workers, who also report reduced visibility at night (Debnath et. al, 2015). There are issues around glare, including difficulty for drivers adjusting to changes in light levels from a relatively dark roadway to a relatively bright work zone (eg, Anani, 2015; van Bommel, 2014) and difficulty for workers completing their tasks. In addition, there are different risks in relation to driver factors at night (ie, higher alcohol, fatigue and speeding prevalence; see section 2.5.2). The question is whether the sites set up for daytime conditions still work at night when there are known issues around glare and visibility and indications of higher risk driver factors. The combination of industry opinion and literature indicates that night condition setups should be an area for further trials and investigation.

6.2 Safety culture and managing the risk of working near live traffic

> *Need a change in culture throughout the industry around the importance of safety on worksites and addressing all risks on site. … Risk assessment rarely is considered unless on major long term capital projects.* (Survey respondent)

Understanding industry worker attitudes and perceptions is important, as while they may not be aware of the objective likelihoods of crashes or exposure to risk, their attitudes and decisions influence the implementation and outcomes of safety measures (Debnath et al., 2015). The survey results of this report revealed positive elements around organisational safety culture, revealing that two in three people feel actively empowered to make changes to improve safety. However, a key challenge around safety culture was that about one in four people still believes risk around live traffic is just a part of the job, indicating a habituation to or shift in risk tolerance around live traffic that comes with increased exposure (eg, Debnath et al., 2015). Further challenges are indicated by ongoing worker behaviour, and that safety is regularly being traded off against cost and traffic flow.

6.2.1 Worker behaviour

Site-specific behavioural indicators of safety from the survey revealed leading indicators around safe behaviours from a worker perspective. This included PPE use (one in four reported workers not always using PPE) and work vehicle movements. It is important to understand why these behaviours are occurring, as opposed to solely bringing in stronger enforcement and auditing of compliance. The industry needs to understand why and any specific site conditions where the safer behaviour becomes more difficult.

A key component of the worker behaviour indicators is that while people state they feel empowered to make changes to improve safety, these same individuals are still observing unsafe behaviours on recent sites. This indicates that they either have not been able to enable change or do not see changes to these behaviours as a safety issue. Either way it indicates that monitoring these behaviours and how these might change over time would be very beneficial.

6.2.2 Trading off safety

About half of those surveyed believed that safety on site was traded off against competing needs like cost and traffic flow. Even in the collection of data around example case studies, the use case for overnight road closure was based on a business case focused on traffic flow interruptions as opposed to defined safety benefits.

All reasonably practicable solutions to improve safety must be evaluated before considering competing needs around cost or delays to traffic flow. TTM needs to be built in earlier and integrated into decision-making around how the work is done, as opposed to a last step once the delivery of construction or maintenance has already been determined. Otherwise, many of the controls (like elimination, or even administrative controls like moving to night work) may not be able to be used, as they are considered too late in the process. The flow-on effect of not doing this can also be under-resourced sites where assumptions have been made around cost (eg, including where spotters are not being used every time). There needs to be a shift in thinking.

6.3 Supporting a consistent approach to evaluating TTM solutions

> *Funding is focused on delivery and no focus on learning.* (Workshop participant)

6.3.1 Promoting case studies

The existing lack of evaluation evidence on TTM solutions is due to multiple reasons. Some of the reasons identified across the workshop and think tank included:

- monetary or resource-related reasons (ie, a lack of funding or clear requirements around evaluation built into contracts)

- perceptions around risks and a compliance culture (ie, trying something that moves away from a rule-based approach to guidance)
- organisational support (including the need to recognise this as part of existing roles and establishing management support for evaluation)
- understanding the end use of the case studies and how these will effect change
- technical capability and confidence in research quality (ie, limited staff training in research and evaluation, which can also relate to lower confidence that the data and insights are of sufficient quality to report on).

In the think tank exercise, there were two main avenues identified and discussed as a solution to overcoming some of these challenges. First, placing some of the requirements into contracting requirements to require increased monitoring and capability building (especially looking at the larger, longer-term contracts such as alliance contracts and network outcome contracts as a start point). Second, assigning a governance body around evaluation of TTM that would report to the Road Worker Safety Governance group. A key challenge for this group would be identifying a funding pathway for evaluation.

6.3.2 Improved safety evaluation of TTM solutions

When asked about the value of better evaluation of TTM solutions, TTM representatives at the workshop revealed that this was all about the ‘confidence we are doing things better’, the ability to learn from simple through to complex sites, encouraging thinking differently around solutions, and improved knowledge sharing.

Crash data at work sites is limited, so the use of near-crash data as a surrogate measure is important. Inconsistencies in what industry reports or identifies as an incident or near miss clearly contribute to underreporting (Blackman et al., 2020; Glaze, 2020). To reduce inconsistency and focus on near misses that have a relationship to crashes, the use of serious ‘near misses’ should be used where crash data is sparse. Serious near misses for the purposes of an easily understood definition used in our survey are unplanned events that have the potential to lead to serious injury or fatality but do not (eg, where a car or work vehicle almost hits a worker). Definitions around TTM setup types or conditions would also benefit from being consistent to understand risk from different types of sites, as the definitions between practitioners, auditors and researchers vary.

In addition to near-miss data, exposure data is lacking in relation to factors like the duration of work activity, number of people on site, and number of person hours. The safety benefits of controls like elimination are difficult to review if exposure data is not readily available. In the survey method the self-reported rate of serious near misses was able to be calculated because exposure and frequency data was captured. A similar exercise needs to occur to monitor, identify and mitigate where risk is occurring at TTM sites more closely. Practically, in relation to effort required, this could be done via annual surveys and during evaluation of trials (ie, self-report or via use of technology). For a wider set of exposure and safety evaluation indicators to consider, see the tables in section 3.4.5.

Finally, it is difficult to assess how well the industry is adopting the risk-based approach unless the use rate of the hierarchy of controls is monitored – for example, kilometres of road network managed or rate of TTM setups approved using different controls. This would be a more direct way to improve the risk-based process and share lessons for the use case for different controls (ie, under different TTM conditions). One mechanism to monitor and promote change would be to examine the practicality of introducing a TTM planning step to opt out of using higher controls (as opposed to opting in, the current approach). An independent review of projects where different controls have been used, including an examination of the opportunities to apply higher controls (if they may have been missed) and capturing an understanding of what could encourage their use, would be beneficial.

6.3.3 On-site safety tools

The TTM industry in New Zealand uses a range of tools and applications at different levels of sophistication and depth to improve safety based on expert on-site observations. The 60-second tool developed and pilot tested in this study revealed that this approach was useable, time-efficient, and useful for considering wider risks once on site. It creates an opportunity for field staff to legitimately assess application of the principles associated with the hierarchy of controls based on new on-site information.

It also offers an opportunity for knowledge sharing around how plans have been adapted to field conditions. Knowledge transfer primarily occurs informally during on-the-job learning from experienced staff identifying areas where changes are required (Thomas et al., 2018). Sharing where change has occurred based on the gap between the plan and the site conditions fosters improved safety in a way that balances planning principles with field insights.

Given that industry practitioners are using these types of tools, there is clear benefit in adopting a consistent approach to reviewing risks and sharing insights from the field around risks. This could include agreement to adopt, trial and adapt this 60-second tool nationally. A consistent approach and the core data received from such a tool are the main benefits, so this would also allow agencies to use their own version. The key component is an agreement on capture and sharing of consistent core data within existing tools (ie, allowing autonomy around additional data capture and process of capture). Benefits to such an approach include:

- enabling consistent, efficient, field-led risk-based assessment
- enabling field staff to legitimately assess and apply safety changes
- providing better data for planners and RCAs around field insights
- providing better data for auditors to support positive change
- enabling knowledge sharing and support around safety changes.

6.4 Ongoing dissemination

Dissemination opportunities were discussed during the workshop and think tank exercise. The key agreed action was that when there were enough case studies around a type of TTM solution, they must be brought together into user friendly data sheets and design notes – for example, following the Waka Kotahi evidence-informed safety design notes (see https://www.nzta.govt.nz/resources/crash-reduction/).

For the longer term, there were discussions around how this information could sit within a larger national library or repository of knowledge – for example, learning from what has been done in the United States (see https://workzonesafety.org/).

6.5 Recommendations

The following recommendations have been put forward for consideration around the risk-based safety solutions (identified from the literature) as well as governance, contracting and monitoring recommendations (based on the survey and workshop insights).

Risk-based safety solutions for TTM

1. Enable the use of the wider set of tools available to avoid and reduce exposure to risk, including:

   a. strategically planning roadworks to ensure worker safety is considered at all stages of the life cycle of any road-related works projects (including long, medium or short-term works)
   b. having processes that require opting out of the more effective risk-based controls like elimination (eg, through road closures) or isolation (eg, physical barriers), as opposed to opting in
   c. using traffic demand management techniques to reduce traffic volumes through work sites (particularly relevant for sites with advanced planning phase)
   d. providing better quality information to drivers about site characteristics (risk is reduced if all aspects of the site relevant to driver behaviour and decision making as they approach the site are effectively communicated)
   e. identifying, evaluating and using site layouts that reduce workers crossing live lanes of traffic (eg, sign simplification techniques)
   f. digitising TTM using sensor technology where appropriate (instantly relay any cone or barrier strikes to controllers), which reduces the need for routine inspections (and improves safety monitoring data) (further research would be beneficial around the use of this technology).
2. Organise an annual, independent review of TTM sites and solutions to identify:
   a. the rate of use of risk-based controls (ie, elimination, minimisation, administrative control measures and PPE)
   b. opportunities for higher controls within this hierarchy
   c. mechanisms to share this knowledge.
3. Consider use of speed camera enforcement where speed limits and speed reduction techniques (such as traffic calming and speed feedback) are not effective.
4. Review TTM solutions for adaptation in poor visibility conditions, particularly night conditions (considering factors such as glare and wet nights).

Governance

5. Establish a TTM solution evaluation sub-group, the duties of which would include:
   a. identifying sources of competitive funding and processes for looking after this funding
   b. building minimum monitoring requirements (following evaluation guidance from this report) into evaluation funding
   c. administering the evaluation case studies at a national level, including delivery of practice notes and communications back to industry
   d. identifying incentives for innovations that aim higher up the hierarchy of controls
   e. developing TTM staff capability, with pathways to developing technical evaluation competency
   f. establishing and monitoring TTM evaluation performance indicators, reporting back to the Road Worker Safety Governance group annually.

Contracting

6. Change language in contracts to include collection and analysis of data to feed into evaluation case studies, especially around larger contracts and alliances (eg, the New Zealand Upgrade Programme, alliance contracts, network outcome contracts).
7. Change language in contracts to include capability building around evaluation and demonstrating evidence of this responsibility within key contractor roles.
8. Develop a competitive research allocation in Waka Kotahi to ensure a diverse range of sites and solutions are covered (ie, not just those from larger alliances).

Monitoring

9. Develop, and agree to use, a consistent industry definition for:
    a. serious near misses (including cause typologies and movement types)
    b. TTM site classification codes
    c. other relevant condition data that will be analysed and reported on by industry.
10. Continue monitoring industry perceptions, culture, and serious near misses (especially causes) annually for comparison with the baseline survey data captured from this study.
11. Enable open, consistent sharing of data from on-site safety tools.

6.6 Limitations

Limitations are naturally inherent in many of the methods used, including within the interviews, industry survey, workshop and think tank – for example, the use of convenience sampling and a focus on perceptions (ie, as opposed to being informed by actual objective data). More specifically, we identified the following limitations and attempted to mitigate them where possible.

- Convenience sampling was used due to the specific nature of the expert sample. Therefore, the results may not necessarily be representative of the geographic distribution of TTM workers. Techniques around leveraging – from support from recognised industry and organisational leaders through to reminder prompts – were used to reduce bias. For elements like looking at changes in attitudes or safety culture, the demographics can be compared to those of future survey respondents to determine similarities/differences and draw conclusions on industry changes (or not).
- The timing of the COVID-19 pandemic could have potential effects in relation to recalling sites or events individuals were likely working on during the data collection period.
- Attitudes around safety culture and the adoption of the risk-based approach were taken at a time where other large changes to TTM were being done (especially changes to national guidance), revealing that there were some attitudes towards change (positive and negative) that could have influenced the results.
- Around testing the guidance, the number of actual case study evaluations of TTM solutions that were provided was very limited. To mitigate this, there was a focus on differing case studies (ie, looking at closures to reduce exposure to risk and early warning signage, as well as more traditional speed countermeasures).
- Survey data reliability may vary based on factors like survey fatigue or even due to limited familiarity with targeted questions (ie, site work questions for office-based workers). Lack of familiarity was mitigated to some extent through filtering questions (office workers did not gain the site-focused question set). An attempt to mitigate survey fatigue was done using randomised split sampling where participants were only asked certain questions (with the trade-off of a lower sample of responses).

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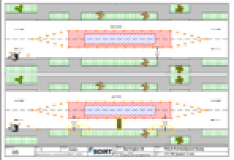
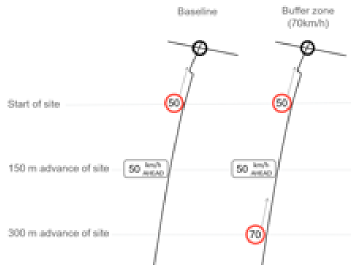
Appendix A: Case studies (Excel format)

			Case Study 1	Case Study 2	Case Study 3
		Name	SCIRT Speed treatments	Remutuka Night Closures	Buffer Speed Zones
		Road name / GPS location	Barrington Street, Christchurch	SH2 between Upper Hutt and the Wairarapa	SH 50 and SH2 Links Road, Napier-Hastings Expressway (GPS -39.563310, 176.852267)
		Problem statement	Speed coming into urban work zone	Exposure to live traffic in narrow conditions	Speed coming into highway work zone
		Evidence of problem	Perceptions of road workers and concerns (quantifiable) and measured speeds (quantifiable)	or ignoring stop signs when encountering stop/go operations)	(quantifiable) and measured speeds (quantifiable)
		Options considered	Removal of TSL; Lane narrowing; speed humps;message board	Positive traffic management / full closure day / full closure night	Buffer speed zone, advanced warning, reduced cone placement, speed feedback signage
		Option selected	Speed humps & lane narrowing	Full closure at night	Buffer speed zone
Site	**Fixed speed zone**		50	**100**	**100**
	TSL speed on road		30	**30**	**50**
	Number of lanes	1		2	
		2	Y	some passing lanes	Y
		3			
		4			
		5			
		6			
	Type of TTM being	Mobile		N	
		Static	Y	Y	Y
		Semi-static		N	
	Specifically designed plan (i.e. not pre-		Y	Y	Y
	Type of Work being done			Cyclical maintenance and/or repairs	New intersection design along new expressway (roundabout)
	Time of day (select all that apply)				Y
		Peak	Y		
		Off-peak	Y		Y
		Day	Y		Y
		Night		Y	
	Road users	Walking	Y		
		Cycling	Y		
		Bus	Y		Y
		HGV	Y	Y	Y
	AADT		16,000	6500	
Exposure data (base estimated for normal activity before any change - add any change numbers into evaluation section)	**Does your case study alter exposure (e.g. fewer people / less time on site / less traffic)?**		N	Y	N
	People	TTM workers during setup/breakdown	unknown		
		Number of TTM during work activity	0		
		Workers if known (not TTM)	unknown		
	Site	Traffic flow while on site (cars/HGV/bus/motorbikes/bikes/pedestrians/scooters)	unknown	0	unknown
		Clearance between traffic lane and workers (m)			
		Type of barrier/protection	None		None
	Setup frequency	Number of times setup/break down of site (per day/week/month)	2 (2 x setup and breakdown of site)		1
	Duration of active work (hours with staff	Active hours (if less than 1 month)	16	4	
		more than one month			Y
	Duration of hours - TTM setup		unknown	4	
	Is the site unattended (at any time)?				

			Case Study 1	Case Study 2	Case Study 3
		Name	SCIRT Speed treatments	Remutuka Night Closures	Buffer Speed Zones
		Road name / GPS location	Barrington Street, Christchurch	SH2 between Upper Hutt and the Wairarapa	SH 50 and SH2 Links Road, Napier-Hastings Expressway (GPS -39.563310, 176.852267)
		Problem statement	Speed coming into urban work zone	Exposure to live traffic in narrow conditions	Speed coming into highway work zone
		Evidence of problem	Perceptions of road workers and concerns (quantifiable) and measured speeds (quantifiable)	or ignoring stop signs when encountering stop/go operations)	(quantifiable) and measured speeds (quantifiable)
		Options considered	Removal of TSL; Lane narrowing; speed humps;message board	Positive traffic management / full closure day / full closure night	Buffer speed zone, advanced warning, reduced cone placement, speed feedback signage
		Option selected	Speed humps & lane narrowing	Full closure at night	Buffer speed zone
Evaluation Factors	**Speed**	Traffic speeds	Y		Y
	Exposure	Exposure reduction (hours/people/traffic)		Y	
	Observations	Near misses worker self report			
		Dangerous maneuvres (overtaking / late stopping / breach)			
		Vehicle hits (e.g. attenuator)			
		Cone or barrier hits			
		assaults)			
	Subjective	Road user comprehension			
		Worker perceptions of safety			
		Unintended consequences (any new risks that have been caused by this setup)			
	Automated data	Camera AI (serious near miss)			
	Other	Other			
Evaluation finding			4.6 kph 85th percentile speed reduction	8 hours / per person - Can we get back to exposure hours total?	Mixed result. One approach increased speed and one approach decreased speed (relative to baseline). Has the potential to shift 85th percentile free speed by 3-4km/h and median free speed by 3-6km/h
General commentary on effectiveness (other observations / insights)				Does require TTM at closure points	Advanced warning beyond 150m (unless queing issues) may limit effectiveness, as drivers cannot see why they are slowing down (i.e. proximity to visible works)

	Case Study 1	Case Study 2	Case Study 3
Name	SCIRT Speed treatments	Remutuka Night Closures	Buffer Speed Zones
Road name / GPS location	Barrington Street, Christchurch	SH2 between Upper Hutt and the Wairarapa	SH 50 and SH2 Links Road, Napier-Hastings Expressway (GPS -39.563310, 176.852267)
Problem statement	Speed coming into urban work zone	Exposure to live traffic in narrow conditions	Speed coming into highway work zone
Evidence of problem	Perceptions of road workers and concerns (quantifiable) and measured speeds (quantifiable)	or ignoring stop signs when encountering stop/go operations)	(quantifiable) and measured speeds (quantifiable)
Options considered	Removal of TSL; Lane narrowing; speed humps;message board	Positive traffic management / full closure day / full closure night	Buffer speed zone, advanced warning, reduced cone placement, speed feedback signage
Option selected	Speed humps & lane narrowing	Full closure at night	Buffer speed zone
Attachment			
Site diagram			
Additional images		 Before: Unsafe working environment and constant stop/go delays for road users.  Night time closures: Safer workers, greater productivity and fewer daytime delays for road users.	 
Links			https://www.nzta.govt.nz/assets/resources/code-temp-traffic-management/docs/2018/Day2-08-Buffer-zones-and-cones-Trialling-intuitive-layouts.pptx

Appendix B: Interview questions

Understanding and perceived benefits of the risk-based approach

Interviewees' background

1. What is your role? How long have you been doing this?
2. What are your responsibilities in relation to TTM safety?
3. Who do you mainly work with (what other roles) to manage site safety?
    - Prompt: This covers both people in your company and people outside of your company.

Incidents and near misses

4. On a typical site how many near misses/incidents occur?
    - Prompt: Are there some sites that seem to have more near misses than others?
5. What would you say is the main type of near miss/incident that is happening?
    - Prompt: Vehicle driven by member of the public into safety/work zone, staff in the wrong place, eg up righting a cone on foot in live lane
    - Prompt: Why?
6. What other types of near misses/incidents are there that are of concern to you?
    - Prompt: Why?
7. What processes are currently in place within your company to record near misses/incidents, specifically in relation to TTM?
    - Prompt: What is the system called? Is there an App you use, paper record, verbal reporting? Have you logged a near miss? How easy is this to use? Any improvements?
8. What information is recorded when a near miss/incident occurs?
    - Prompt: Location, number of people involved, weather and road conditions etc.
    - Prompt: Sharing the near miss template with us might make this easier if you are able to do so.

Key risks and decisions

9. What would you say are the key risks around TTM?
    - Prompt: Getting to the site, site setup, during the live site, breaking the site down, travelling back from the site?
10. What currently works well for you in managing these keys risks?
    - Prompts:
        - What processes are in place?
        - Who do you go to for a second opinion if you are concerned about a site setup?
        - Is there any additional health and safety training or practical on-site training that helps you?
        - What is the debrief process / lessons capture or sharing for when things don't go right?
        - What could be changed to help you better manage these risks?

11. How familiar are you with the ‘risk-based approach’ with its hierarchy of controls? Do you already apply it in your work?
    - Prompt: Health and Safety at Work Act 2015 use of hierarchy of controls:
      - Eliminate
      - Minimisation
        - Substitution (wholly or partly) and/or
        - Isolation/Preventing contact and/or
        - Engineering control measures
      - Administrative control measures
      - Personal protective equipment (PPE)
12. Which of the types of controls are not done well at the moment in your opinion (eliminate / minimisation / admin controls / PPE)?
13. What benefits do you find, or would find, to applying the risk-based approach to TTM?
    - Prompt: Do you think such an approach would help you improve safety?
14. What challenges, if any, do you face in applying this ‘risk-based approach’. If you are not currently using this ‘risk-based approach’ what would you think the challenges be to start using it?
    - Prompt: Would it be an issue to change already in place safety process to use this approach? Would it be seen as difficult to manage across all aspects of the TTM, from planning to implementation? Cost/resources change?
15. **STMS/TC only**: How comfortable are you in changing, or making suggestions to change, the TMP when on site to reduce a previously unidentified risk?
    - Prompt: Is there a formal process that is easy to do this that you have no issues with using?
16. Would you like to add anything else?

Appendix C: Workshop Miro board post-its

I. How well does this approach fit with your process?

II. What would support better monitoring?

III. What are the barriers to monitoring right now?

IV What is the value of monitoring?

Appendix D: 60-second tool

* 1. Now you are on site, do the following conditions match with what was expected by your safety planning? *[i.e. your existing safety controls are enough]*

	Yes	No *(Higher risk than expected)*
Vehicle speeds (as expected or lower)	○	●
Vehicle volume or flow (consider queues)	●	○
Number of pedestrians or cyclists (consider nearby schools or bike lanes)	●	○
Curves in the road or slope (consider viewing distance and ability for trucks or cars to stop safely)	●	○
Available space (e.g. roadside features / signs causing blockage to any user path: car, truck, cyclist, pedestrian)	●	○
Road conditions (e.g. worn or ghost line markings, or poor skid resistance)	●	○
Weather conditions (e.g. reduced visibility and ability for trucks or cars to stop safely)	●	○
Light conditions (e.g. twilight, or shift from day to night conditions)	●	○
Visibility of safety devices (i.e. visibility of existing or temporary signs or markings)	●	○
Staff / equipment (consider numbers or condition of staff, e.g. fatigue, or equipment e.g. damaged/ non-reflective signs)	●	○
Physical separation between workers and road traffic (consider both distance to live traffic and use of barriers)	●	○
Other nearby work sites (within about 3 km that could impact your site)	●	○

Next

2. We will make on-site CHANGES to manage these risks [Tick to confirm all of these risks are being managed]

- [ ] Vehicle speeds (as expected or lower)
- [ ] No. We will STOP WORK until the Safety Plan is changed

Prev Next

3. What on-site changes are you making to manage the risk?

4. Has this adequately managed the risk?

- ◯ Yes
- ◯ No. STOP work until the safety plan is changed

Prev Next

Thank you. You are helping everyone get home safe

Done

Appendix E: Survey

Temporary Traffic Management Survey

Thank you for taking the time to complete this anonymous survey. The purpose of this study is to give our TTM industry a voice about where we are seeing risks, understand how well we are applying risk-based controls (from cones to closures), and checking in on our current safety culture.

1. What best describes your role right now?

- O Site Traffic Management Supervisor/Specialist (STMS)
- O Traffic Controller / Traffic Management Operative (TC / TMO)
- O Traffic Management Planner / TTM Planner
- O Temporary Management Plan Approver
- O Traffic Management Coordinator (TMC) / Inspector (TC-I)
- O Road Controlling Authority (RCA)
- O Road worker/Road contractor
- O Traffic Management Supervisor
- O Office based/other management role
- O Auditor
- O Other (please specify)

2. How many years' experience do you have working with Temporary Traffic Management?

- O Less than 1 year
- O 1–3 years
- O 3–5 years
- O 5–10 years
- O 10+ years

* 3. Are you often on site, with temporary traffic management sites as part of your job?

- O I am regularly on site
- O I am not usually on site as part of my job

[Logic: this question was used to identify those that were on site regularly. This determined the sections of the survey available to the participant]

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Temporary Traffic Management Survey

Perceptions of safety

4. How safe do you typically feel when you are working under the following conditions?

	I have never experienced this site condition	Not safe at all	Somewhat unsafe	Neither safe or unsafe	Somewhat safe	Very safe
At static or fixed work/construction sites	○	○	○	○	○	○
At mobile sites (eg. vegetation clearing)	○	○	○	○	○	○
At sports and events sites	○	○	○	○	○	○
At sites with barriers	○	○	○	○	○	○
At sites without barriers (e.g. use of cones)	○	○	○	○	○	○
At sites outside of daylight hours	○	○	○	○	○	○

---------------------------- (next page)

[Logic: Split-method approach, for those who selected they were not on site regularly – and also 50% of respondents who selected they were on site regularly]

Temporary Traffic Management Survey

How we control our risks

5. In your experience, how often do you believe the following are applied to reduce risk when working on Temporary Traffic Management sites?

	Very rarely	Rarely	Occasionally	Very frequently	Always	Not sure
Use personal protective equipment (PPE): Use or wear items (e.g. high visibility equipment and clothing, hard hat and safety boots).	○	○	○	○	○	○
Apply administrative control measures: Use safe methods of work, procedures or processes (e.g. doing night work when there is less traffic).	○	○	○	○	○	○
Eliminate: Removed sources of risk (eg. closing the road)	○	○	○	○	○	○
Isolation: Separate people from the source of risk (eg. physical barrier system)	○	○	○	○	○	○
Apply engineering controls: Changing components of the work area (e.g. narrowing lanes to reduce vehicle speeds)	○	○	○	○	○	○
Substitute: Swap with something that has a lower risk (eg. using temporary traffic lights instead of a manual traffic controller)	○	○	○	○	○	○

6. How do you think these controls are ranked in order of effectiveness at reducing risk?

- [ ] **Isolation:** Separate people from the source of risk (eg. physical barrier system)
- [ ] **Substitution:** Swap with something that has a lower risk (eg. using temporary traffic lights instead of a manual traffic controller)
- [ ] **Use personal protective equipment (PPE):** Use or wear items (e.g. high visibility equipment and clothing, hard hat and safety boots).
- [ ] **Apply administrative control measures:** Use safe methods of work, procedures or processes (e.g. doing night work when there is less traffic).
- [1] **Elimination:** Removed sources of risk (eg. closing the road)
- [ ] **Apply engineering controls:** Changing components of the work area (e.g. narrowing lanes to reduce vehicle speeds)

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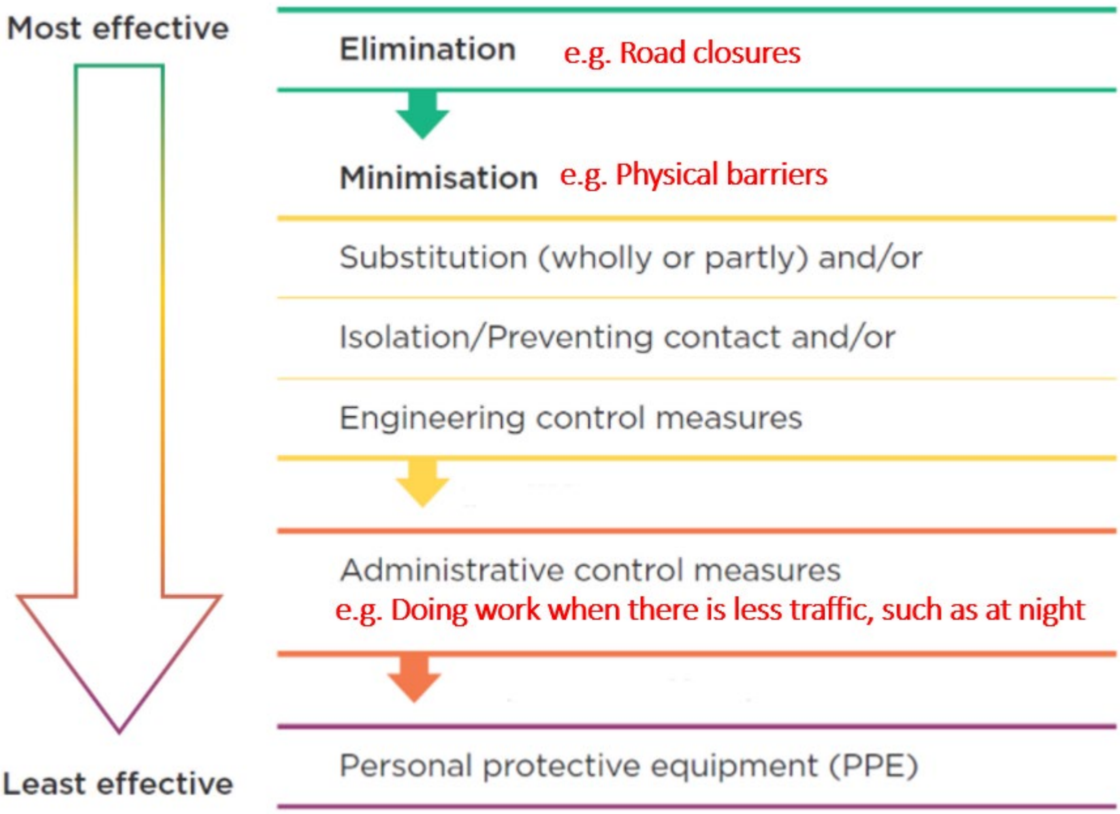
Temporary Traffic Management Survey



*7. Still thinking about the approach and the controls used to manage risk in the image above, what best describes you?

- O I have been actively doing this in my own work and encouraging others to do this
- O I am doing this in my own work
- O I like the idea of this approach, but some of this is difficult to do
- O I believe this approach is difficult

8. How well do you understand this approach and these controls?

I really do not understand this

I understand this and all of these controls completely

---------------------------- (next page)

[Logic: only shown to those who selected 'I believe this approach is difficult' on previous page]

9. What do you think are the barriers to this approach and these controls [please tick all that apply]?

- O Cost
- O Time
- O Public acceptance (traffic flows)
- O Understanding of the benefits (eg less time on site, safety outcomes)
- O Other (please specify)

---------------------------- (next page)

Temporary Traffic Management Survey

Your organisation and the industry right now

10. Please select your level of agreement with the following statements

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
We get timely feedback on the safety issues we raise.	○	○	○	○	○
I am prepared to speak to my direct manager when unsafe situations are developing.	○	○	○	○	○
Pointing out safety concerns can easily be seen as unnecessary hassle	○	○	○	○	○
In temporary traffic management right now, near misses are just part of the job	○	○	○	○	○
There is sometimes pressure to put customer traffic flow before safety	○	○	○	○	○
I am aware of situations where there was fewer people or less equipment than planned	○	○	○	○	○
Good proposals for how to improve safety are often stopped if they cost too much	○	○	○	○	○
Working next to live traffic makes accidents unavoidable	○	○	○	○	○

---------------------------- (next page)

[Logic: section of survey only presented to the other 50% of respondents who selected they were on site regularly]

Temporary Traffic Management Survey

Complex Worksites

When answering these questions please think about a complex work site you have been on recently. By complex, we just mean a site where something at the location made you consider the risks more than usual (such as limited space or view, or different traffic conditions).

* 5. Thinking about the last complex worksite you were on, was the site static, semi-static or mobile?

- O Static / Fixed site (ie site was set up in one place)
- O Semi-static (ie short-term operation, less than 1 hour)
- O Mobile (ie the site moves along an area)

6. Thinking about the last complex site, which of the following best describes the road location?

- O Urban
- O Suburban
- O Rural

7. Still thinking about the last complex worksite you were on, what best describes how traffic was managed?

- O No lane closures (eg work on the road shoulder / road side)
- O Reduced lane width
- O Lane closures
- O Single-lane alternating flow (stop go with either MTC or portable traffic lights)
- O Full closure

8. How long was this complex site running for?

- O Up to 8 hours
- O 8–24 hours
- O 2–7 days
- O 8–30 days
- O Longer than 1 month

9. Still thinking about the last complex worksite you were on, please read the following statements and select the option you believe best fits how often you observed any of the following behaviours

	Did not occur at this site	Very rarely	Rarely	Occasionally	Very frequently	Always	N/A
Drivers followed the temporary speed limit beside the working space	○	○	○	○	○	○	○
Drivers had trouble navigating the site (e.g. knocked down cones)	○	○	○	○	○	○	○
Drivers ignored traffic controllers	○	○	○	○	○	○	○
Drivers were aggressive or abusive	○	○	○	○	○	○	○
Workers used full PPE correctly (Personal Protective Equipment)	○	○	○	○	○	○	○
Workers crossed the live lane when traffic was present	○	○	○	○	○	○	○
Workers had a spotter when needed	○	○	○	○	○	○	○
Unsafe work vehicle movements (e.g. reversing trucks)	○	○	○	○	○	○	○

10. Still thinking about the last complex site you were on, how would you rate your safety during the following?

	Not safe at all	Somewhat unsafe	Neither safe nor unsafe	Somewhat safe	Very safe	N/A
Planning phase	○	○	○	○	○	○
Travel to the worksite	○	○	○	○	○	○
Setting up the worksite	○	○	○	○	○	○
Travel between worksites (if any)	○	○	○	○	○	○
Managing traffic during work space activity	○	○	○	○	○	○
Breakdown of the site	○	○	○	○	○	○
Travel from the worksite	○	○	○	○	○	○

* 11. Still thinking about the complex site, how many near misses did you observe or hear about? [Note: Near misses are unplanned events that did not result in injury or damage but had the potential to do so. For example, where a worker trips over but does not suffer an injury.]

O No near misses
O 1
O 2–3
O 4–6
O 6–9
O 10 or more
O Not sure

---------------------------- (next page)

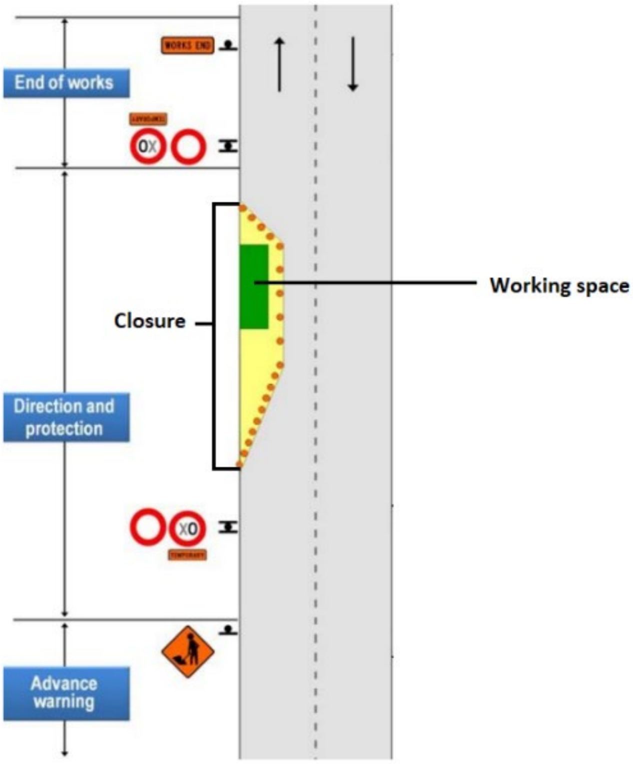
Temporary Traffic Management Survey

Serious near misses

Near misses are unplanned events that did not result in injury or damage, but had the potential to do so. For example, where a worker trips over but does not suffer an injury.

Serious near misses: Are those near misses that had the potential to result in serious injury or fatality. For example, where a car or work vehicle almost hits a worker.

Please take a moment to look at the following image before answering the next question.



*12. Thinking about a recent serious near miss on site, where on the site did the near miss occur? (see example image above)

- O Advanced warning zone
- O Closure zone (yellow and green in diagram above)
- O Direction and protection zone (in the live lane)
- O End of work zone
- O I can't think of any serious near misses on sites I have been to
- O Other (please specify)

---------------------------- (next page)

[Logic: presented to all who answered the previous question and did not select 'I can't think of any serious near misses on sites I have been to']

* 13. Still thinking the same serious near miss on site, what do you think were the main contributing factors? [Please tick up to 3 factors]

- ☐ Improper site setup (eg missing signs or traffic control devices, or traffic controller not in place)
- ☐ Complexity of site (eg number of vehicles/people interactions)
- ☐ Road user error – failed to follow instructions from traffic controller
- ☐ Road user error – travelling too fast
- ☐ Road user queues causing lack of advanced warning
- ☐ Worker driver error (eg trucks or machinery reversing)
- ☐ Worker pedestrian error (eg distraction / moving into an unsafe zone)
- ☐ Worker vehicle factors (eg warning systems on machine, protective fittings of machine)
- ☐ Environmental factors (eg wet conditions)
- ☐ Environment factors – artificial lighting (eg insufficient for conditions)
- ☐ Other (please specify)

14. Who was at most risk of serious injury?

- O Public driver
- O Public cyclist, pedestrian
- O Temporary traffic management worker – Walking
- O Temporary traffic management worker – In vehicle
- O Work zone worker – Walking
- O Work zone worker – In vehicle

15. Please briefly describe what happened

16. What do you think could have been done to prevent the near miss?

--------------------------- (next page)

[Presented to all participants]

Temporary Traffic Management Survey

Demographics

11. What is your age? [Drop down menu]

Under 20
20-24
25-29
30-39
40-49
50-59
60-64
65-69
70-74
75-79
80 or older
I prefer not to say

12. Where are you located? [Drop down menu]

Northland, Te Tai Tokerau
Auckland, Tāmaki Makaurau
Waikato
Bay of Plenty, Te Moana-a-Toi
Gisborne, Te Tai Rāwhiti
Hawke's Bay, Te Matau-a-Māui
Taranaki
Manawatu-Wanganui, Manawatū-Whanganui
Wellington, Te Whanganui-a-Tara
Tasman, Te Tai-o-Aorere
Nelson, Whakatū
Marlborough, Te Tauihu-o-te-waka
West Coast, Te Tai Poutini
Canterbury, Waitaha
Otago, Ōtākou
Southland, Murihiku

13. Which ethnic group do you belong to? (Select all that apply)

- ☐ New Zealand European
- ☐ Other European
- ☐ Māori
- ☐ Samoan
- ☐ Cook Islands Māori
- ☐ Tongan
- ☐ Niuean
- ☐ Chinese
- ☐ Indian
- ☐ Middle Eastern / Latin American / African
- ☐ Pacific peoples
- ☐ Asian
- ☐ Other (please specify)

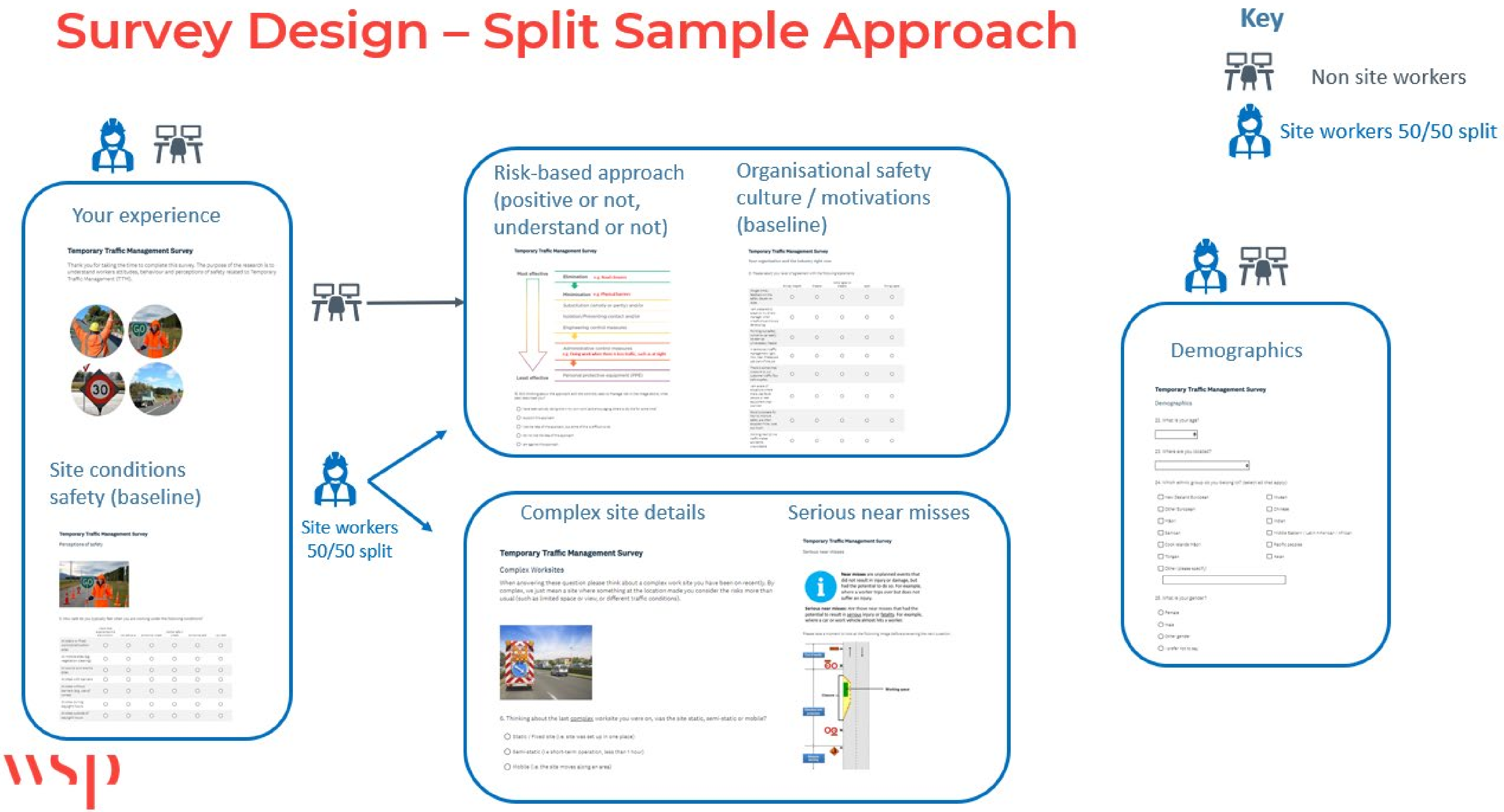
14. What is your gender?

- O Female
- O Male
- O Other gender
- O I prefer not to say

15. Do you have any comments you would like to make in relation to site safety, risks you are seeing, or improvements you would like to see?

[End of survey]

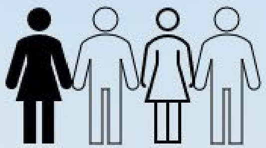
Appendix F: Split-method design



Appendix G: PowerPoint report of survey results

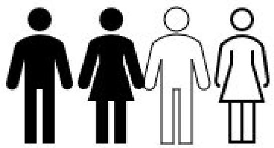
We asked about safety culture

Attitudes towards near misses and accidents on site



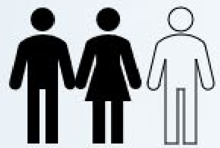
1 in 4 people believe risk around live traffic is a part of the job.

Trading off safety



Around half of people believed that safety on site was traded off against competing needs like cost and traffic flow.

Empowerment

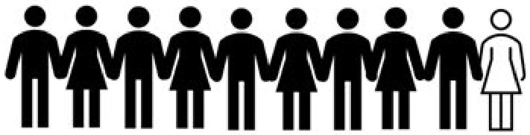


2 out of 3 people feel empowered to actively make changes to improve safety.

We asked about the risk-based approach to TTM

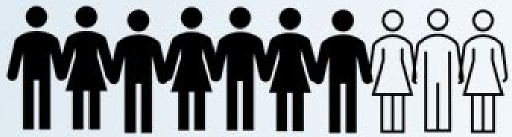
wsp

Confidence in understanding



9 out of 10 people have some confidence in their understanding of the controls in a risk-based approach.

Willingness to adopt the risk-based approach

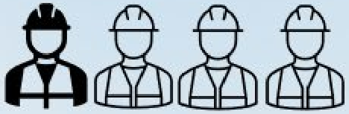


6 in 10 people are willing to adopt the risk-based approach.

Others like this approach but find it difficult to do. Cost, time and public acceptance are challenges.

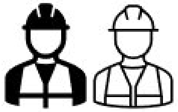
We asked about the last complex site you have worked on

PPE



1 in 4 people indicated that workers did not always use full PPE.

Spotters



Only half of workers always had a spotter when needed.

Work vehicle movements

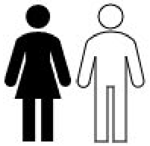
1 in 4 people indicated that unsafe work vehicle movements are occurring.

We asked about the last complex site you have worked on

Speed limits

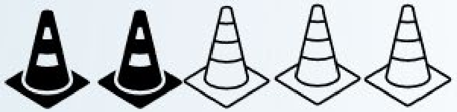
Workers' views are that public drivers are not following the speed limit at work sites.

Public driver response



Over half of respondents experienced aggression or abuse from public drivers.

Site understanding



2 in 5 workers reported public drivers had trouble navigating the site.

We asked about near misses at complex work sites

Near miss occurrence

Near misses are occurring.

2 out of 3 people observed or heard about a near miss at the last complex site they worked on.

Site type

Sites with **single-lane alternating flow setups** (stop/go with either MTC or portable traffic lights) had the highest rate of near misses.

Site type

Sites with **reduced lane width** had the lowest rate of near misses.

Temporary Traffic Management

Attitudes and behaviours survey

Results

F. Thomas, J. Thomas, L.. Malcolm, F. Tate
WSP Research

Purpose

The survey is intended to be a baseline survey to understand workers' current attitudes and behaviours to TTM sites, designed with the ability to be used repeatedly for comparisons over time. The survey captures:

- Attitudes to TTM sites, including work/construction sites, sports and events
- What are the current safety behaviours – what's being done well, what's not, risks and exposures
- Understanding near miss data and attitudes to the risk-based approach.

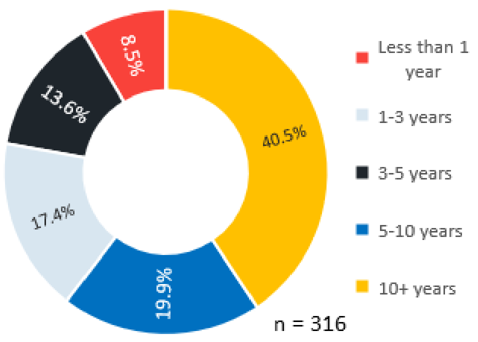
Survey method

- A survey was distributed via multiple channels including personal communications, the Waka Kotahi critical risk team and TTM industry newsletter. Both online and paper-based surveys were available.
- Responses were collected from April to June 2022.
- A split sample survey approach was used to reduce the length of the survey time while still aiming to achieve all the desired research objectives. The number of responses for each section is included.

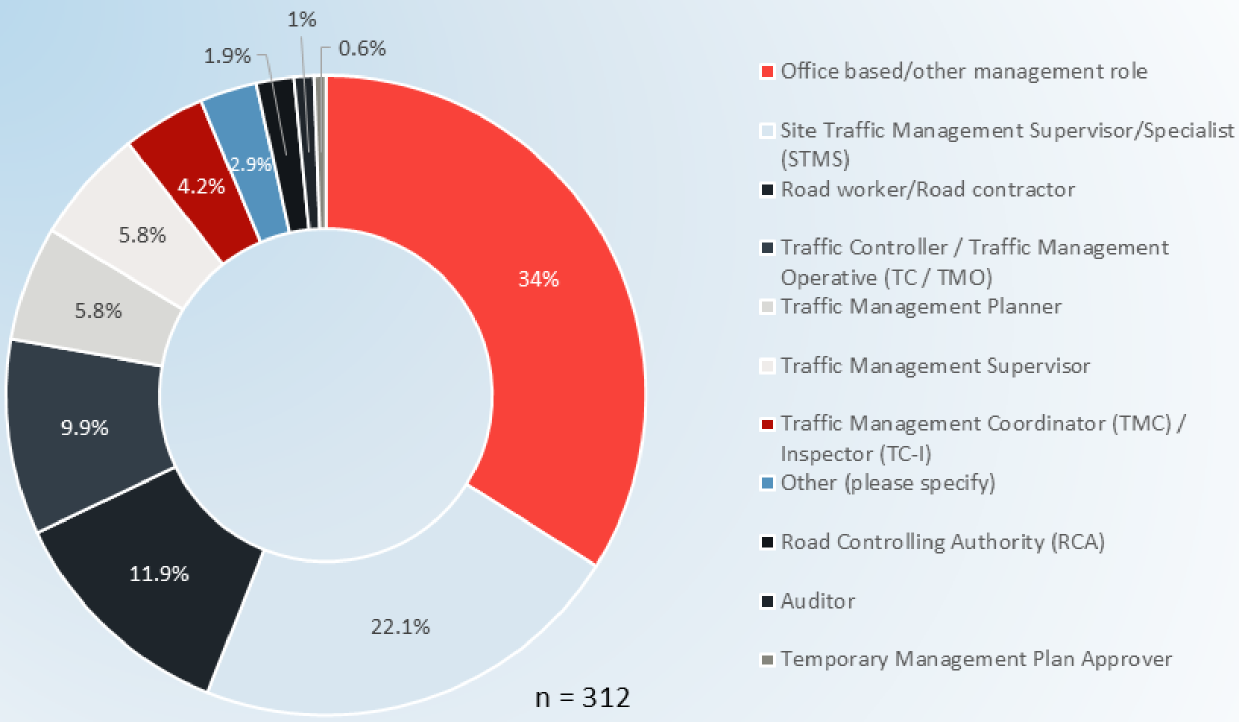
9

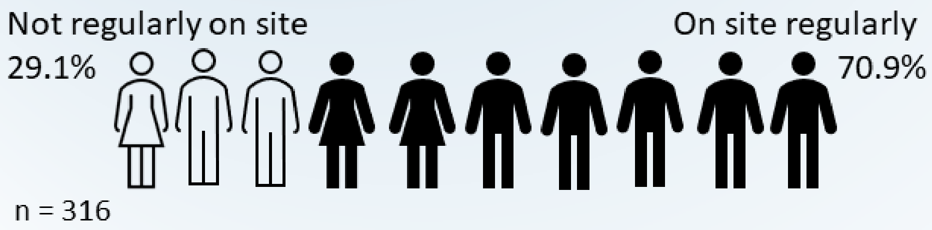
Demographics

The majority of participants indicated being on site regularly and had been in the industry for more than 5 years.

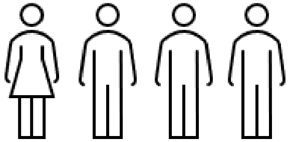


1/3 of respondents indicated they held an office-based or other management role.





Gender

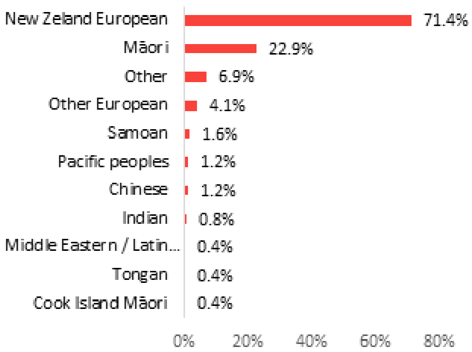


n = 204

Of respondents who reported their gender, females comprise roughly one quarter of responses (28.4%).

Ethnicity

Respondents were largely of New Zealand European and Māori descent.

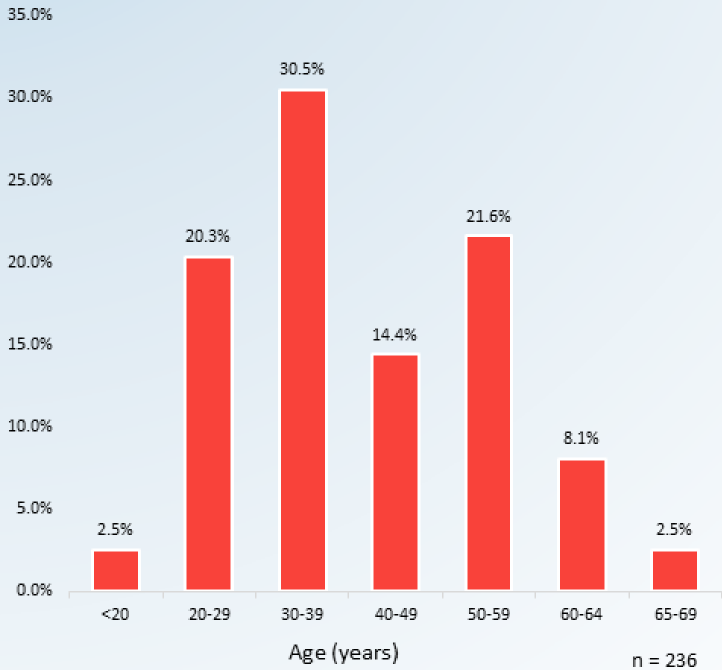


n = 245

Age

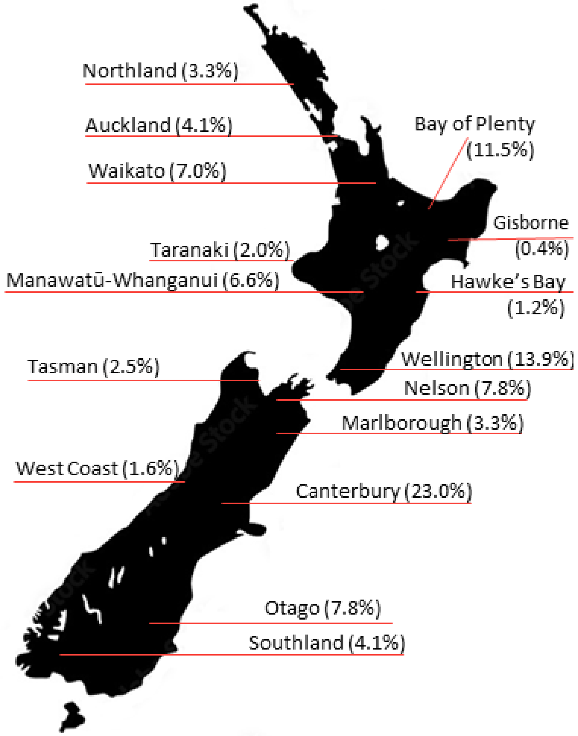
The majority of respondents were under the age of 40 (53%), with a further 35% between the ages of 40 and 60 years.

Only 2.5% of respondents indicated being under 20, with a further 2.5% being over 65.



n = 236

Location



n = 244

Organisational safety culture

Respondents were asked to rate their level of agreement with eight items related to the organisation and industry as it is currently.

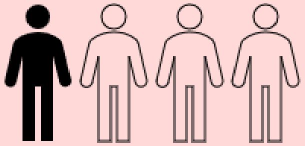
12

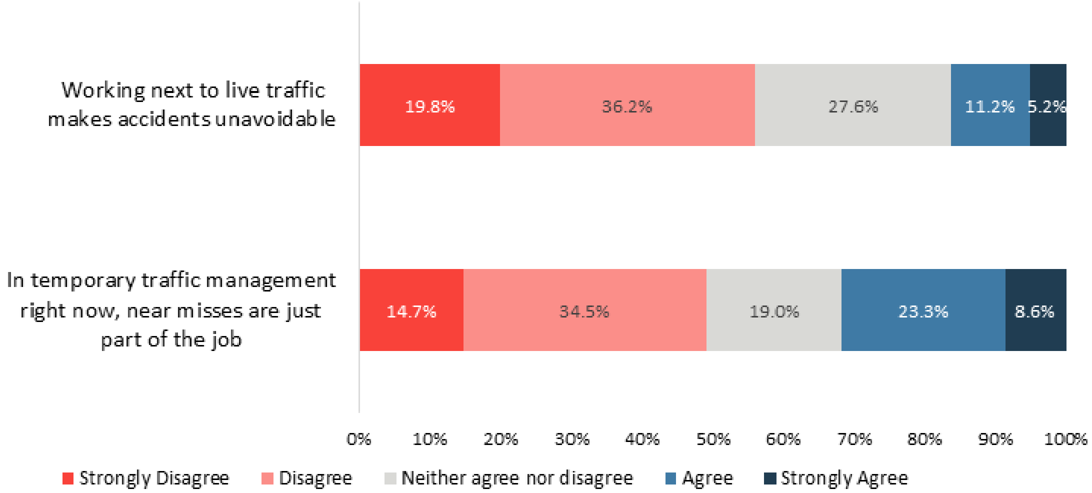
Safety culture

Attitudes towards near misses and accidents on site

Attitudes towards near misses and accidents on site

1 in 4 people believe risk around live traffic is a part of the job.





n = 116

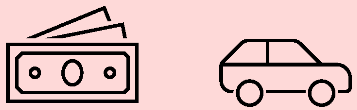
13

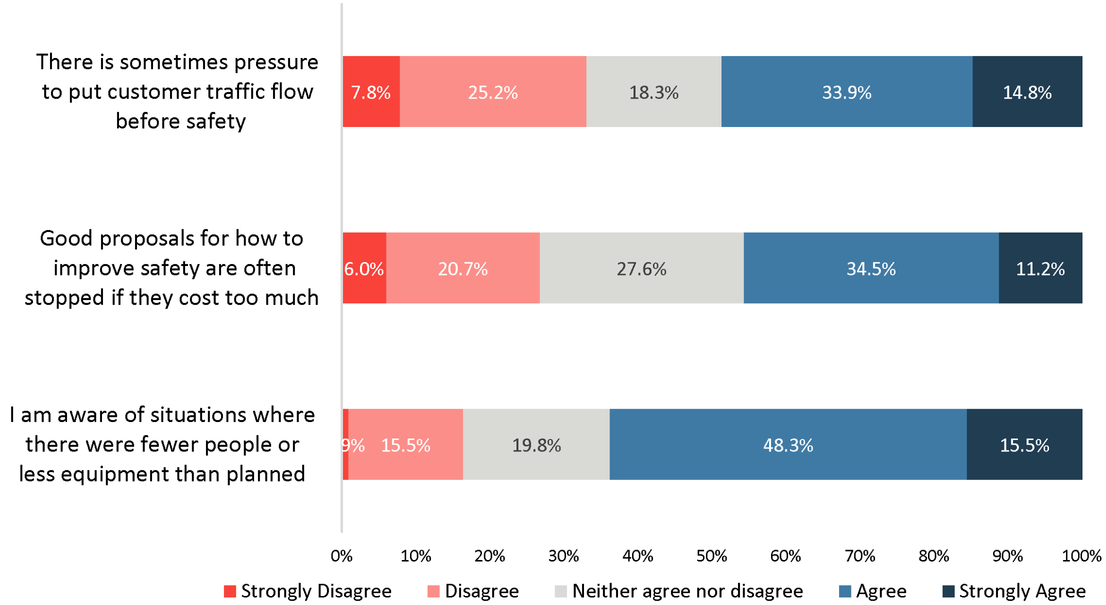
Safety culture

Trading off safety

Trading off safety

Approximately half of the respondents believed that safety on site was traded off against competing needs.





n = 116

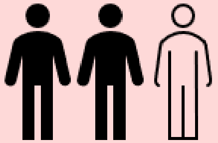
14

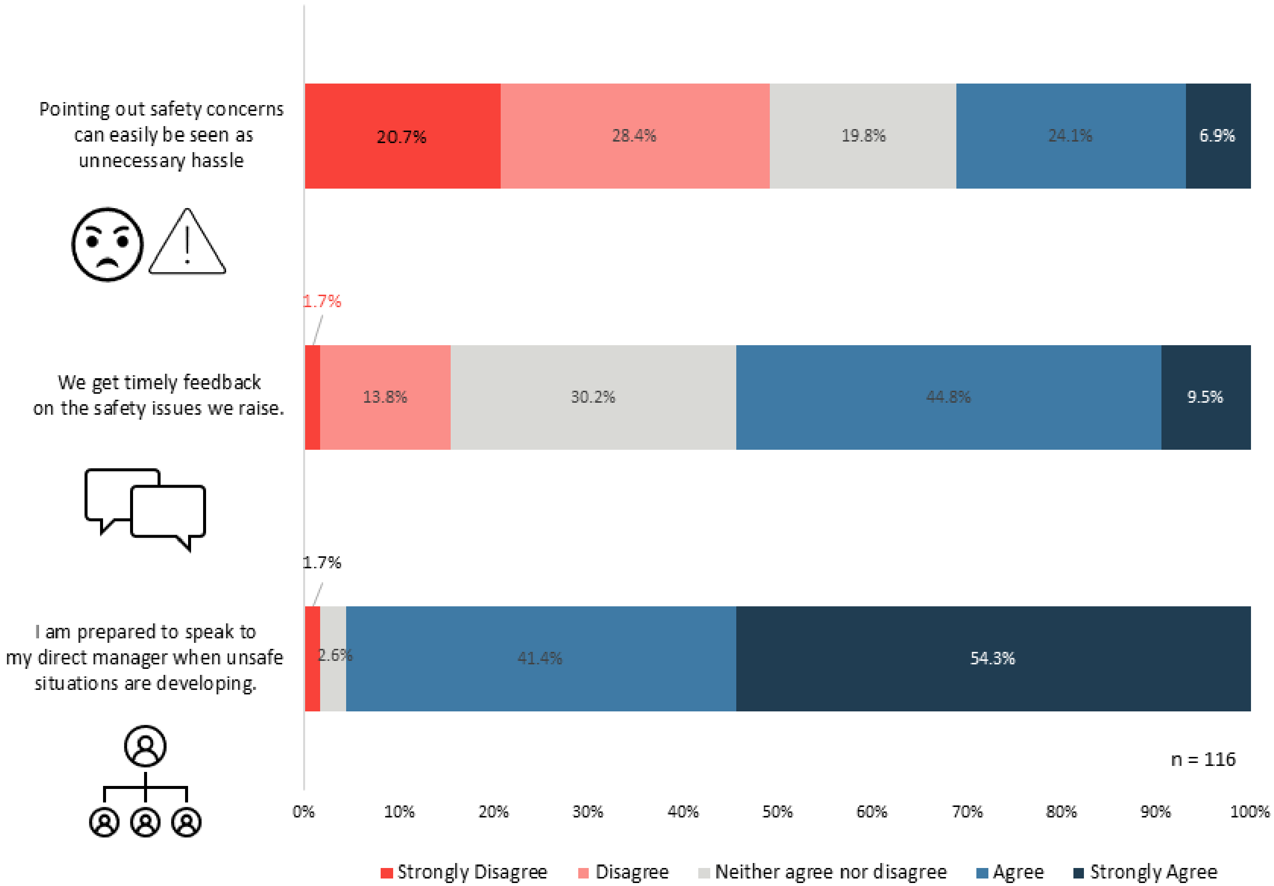

Safety culture
"RCA sometimes does not take safety as a priority if it creates queues. I am currently experiencing this and am having to push back resulting in the job possibly getting delayed."
"Require adequate budgets for TTM as we constantly strike sites where the contractor is choosing between having budget blowouts or trying to minimise TTM to preserve their margins. This is simply unacceptable."
15

Safety culture

Empowerment

2 out of 3 people feel empowered to actively make changes to improve safety.





Safety culture

"Need a change in culture throughout the industry around the importance of safety on worksites and addressing all risks on site. ... Risk assessment rarely is considered unless on major long-term capital projects. There needs to be a step change in the industry to lift professionalism, at the moment it is a race to the bottom."

17

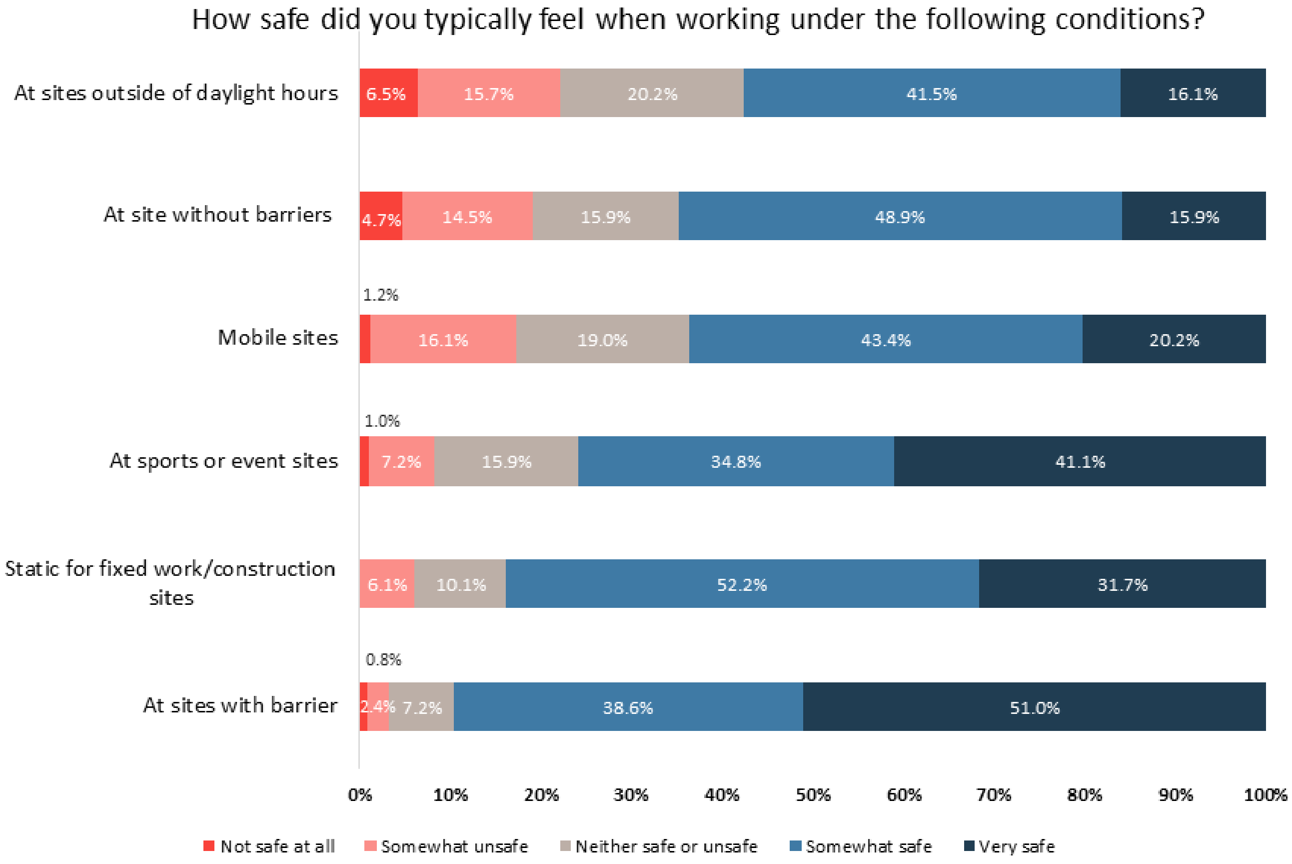
Safety culture

Perceptions of safety

Respondents rated working on sites outside of daylight hours as the least safe condition.

Respondents reported higher perceptions of safety when working at sites that had barriers compared to those that did not have barriers.

Mobile sites were perceived as less safe than static/fixed work sites.



Safety culture

"There have been good improvements in site safety in the last few years. I am particularly impressed with the use of large concrete barriers to protect installers of wire-rope barriers … keep up the good work."

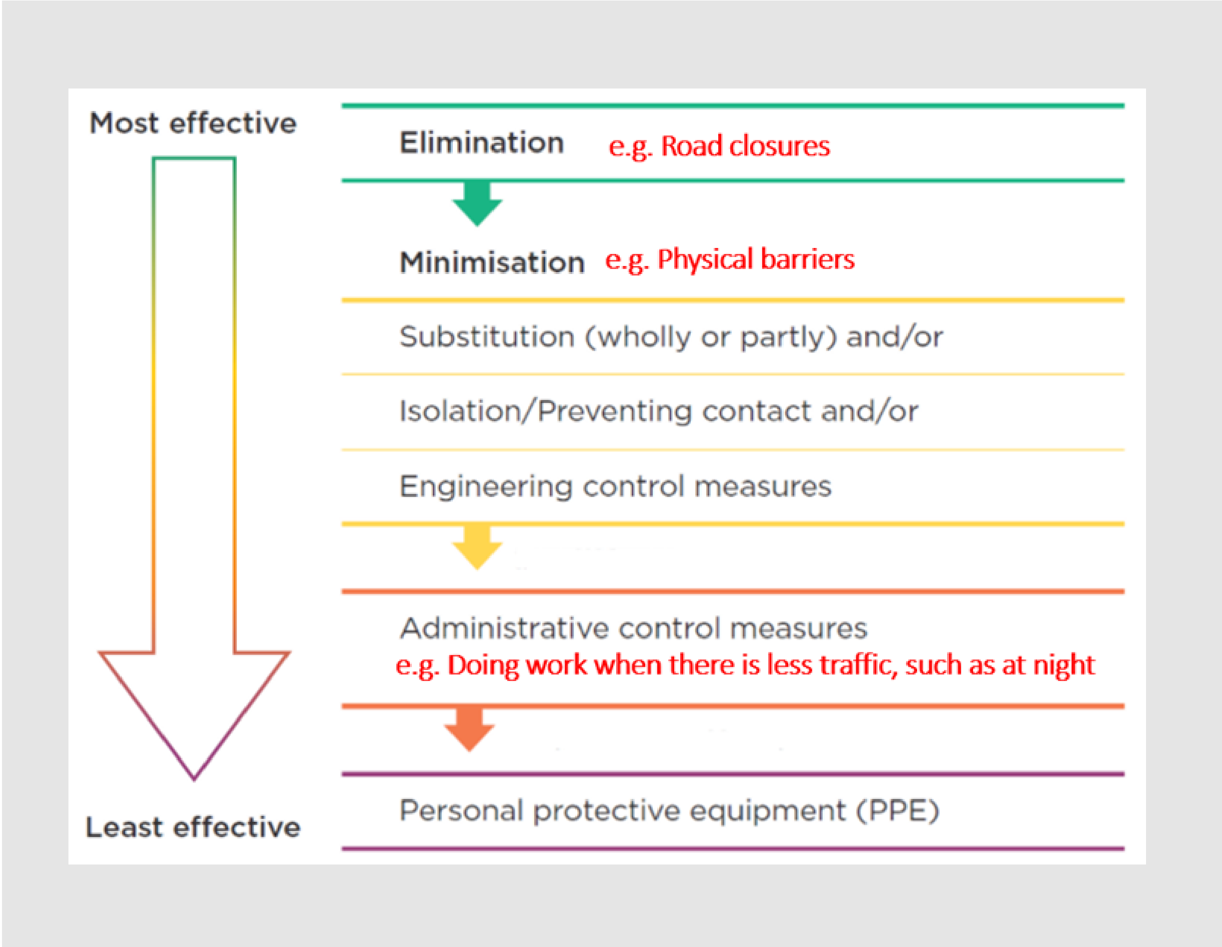
"… in your goal of safety you have reflective signs for night driving, great, however they are that bright they reflect back at you and actually cause distraction and eye stress. Add some rain and it becomes dangerous. You can't read the sign till you're practically on it as it was just a reflective mess before you could read it anyway."

"The use of orange PPE especially at night makes the workers merge with the signage and delineation. This is worse in wet weather and glary situations. Should consider a different colour for PPE or TTM equipment".

19

Risk-based approach

Respondents answered a number of questions relation to the risk-based approach



20

Risk-based approach

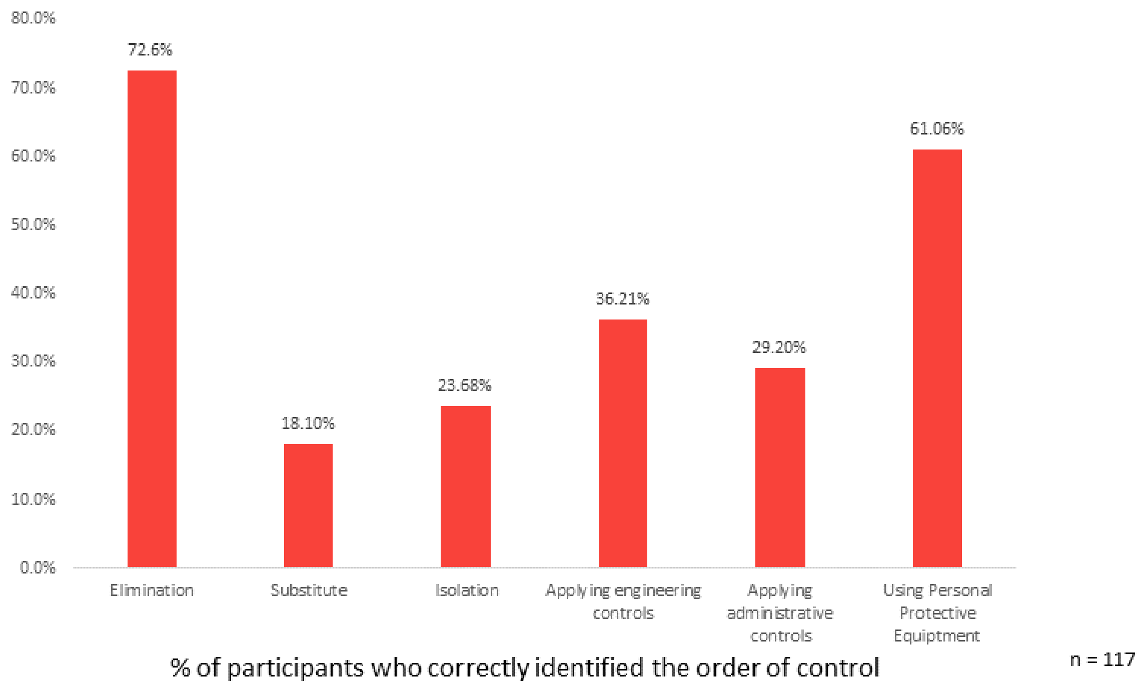
Understanding of the risk-based approach

Ranked order of control

To get an idea of workers' understanding of the risk-based approach, workers were asked to rank each of the controls based on their order of effectiveness.

The majority of respondents were able to correctly rank Elimination as the most effective control, and use of PPE as the least effective control.

There was less success in relation to the controls that fell between the most and least effective controls.



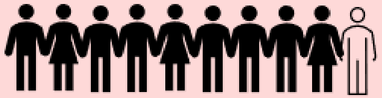
21

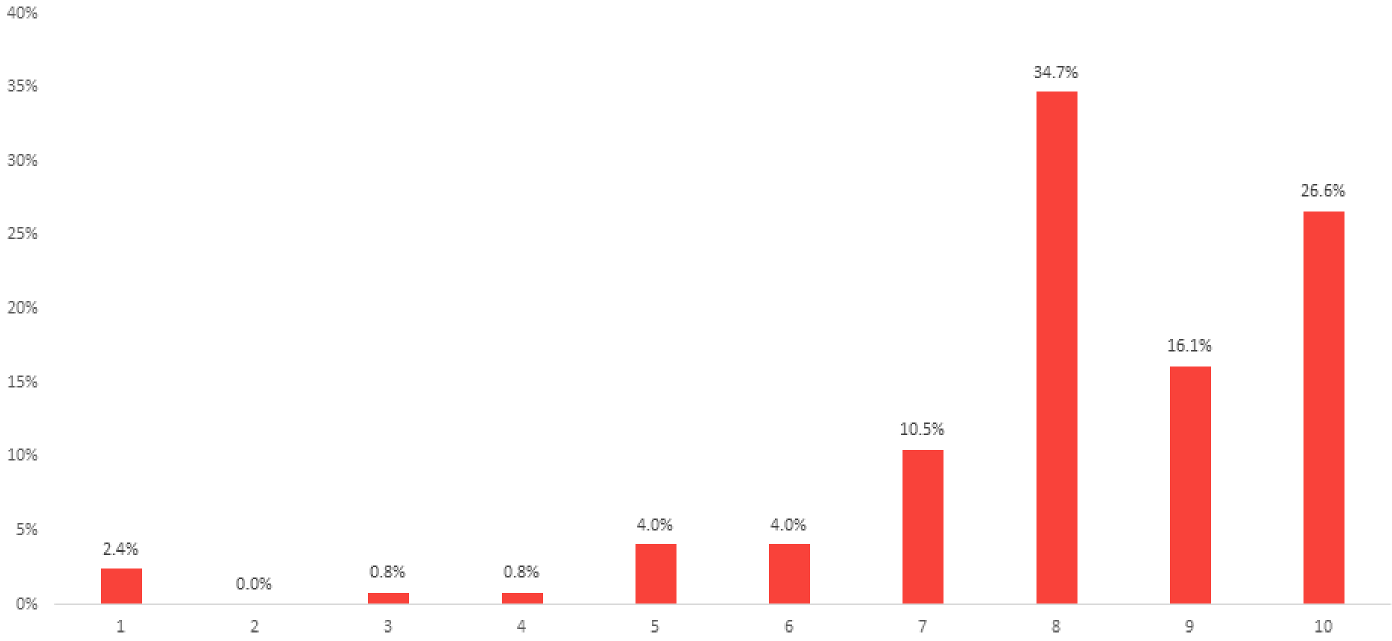
Confidence in understanding

Risk-based approach

How well do you understand this approach and these controls?

9 out of 10 have some confidence in their understanding of the controls under a risk-based approach.





I really do not understand this

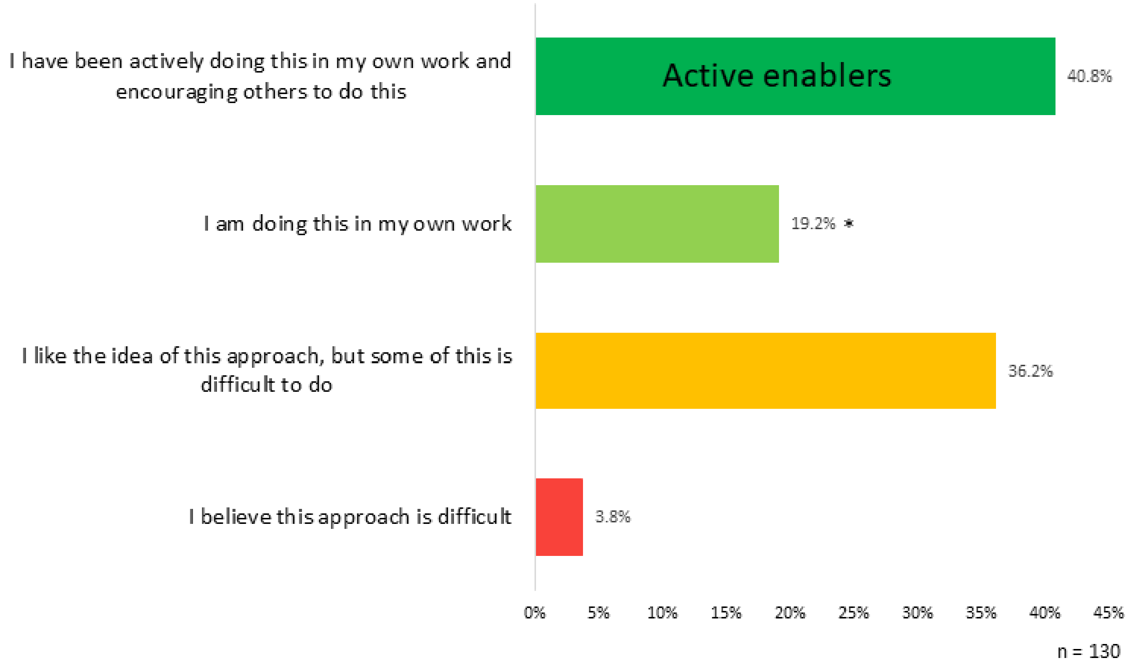
I understand this and all of these controls completely

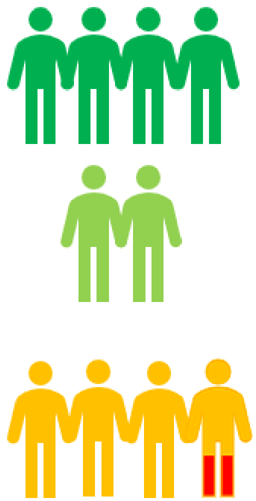
22

n = 124

Willingness to adopt

Risk-based approach





6 in 10 people are willing to adopt the risk-based approach.

Cost, time and public acceptance are challenges for adoption of the risk-based approach

* Workers who are on site regularly were more likely to select this option.

No significant differences between genders were found.

23

Risk-based approach

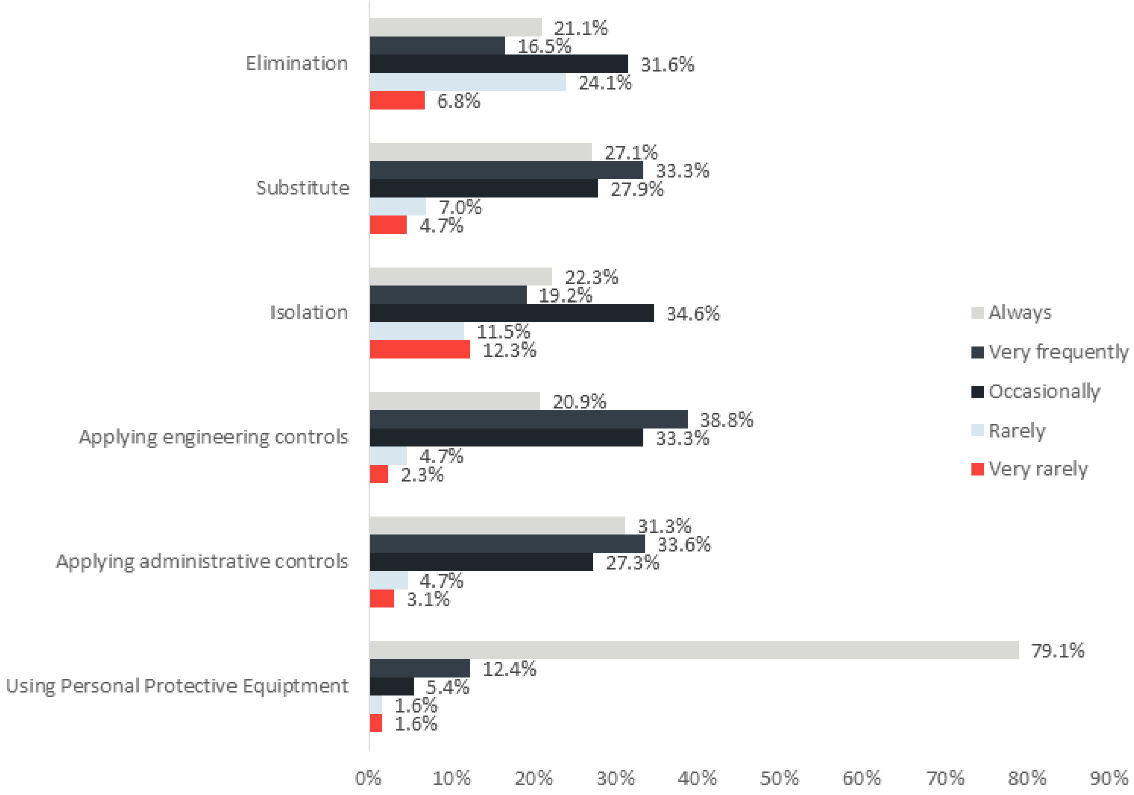
Frequency

Responses indicate the perceptions of workers in relation to frequency of each risk-based approach control.

This provides insight into where improvements can be made:

- Either through physical changes (e.g. more barriers and higher use of PPE)
- Or providing information to shape workers' perceptions (e.g. planning documents showing how the risk-based approach is applied to sites).

How often do you believe the following are applied to reduce risk when working with TTM sites?



Risk-based approach

"Not enough TTM staff understand risk and how to minimise this risk to themselves and road users. Competency needs to be lifted significantly with support from management. Management also needs to provide adequate training and resource/equipment to front line staff to allow them to do their job safely."

25

Complex site analysis

When answering these questions respondents were asked to think about a complex work site they had been on recently.

By complex, we are referring to a site where something at the location made you consider the risks more than usual (such as limited space or view, or different traffic conditions).

26

Complex site analysis

Last complex site

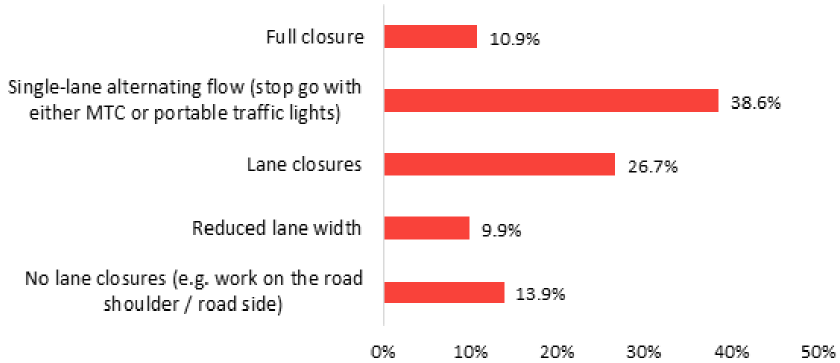
Most were in urban (42.6%) or rural areas (38.6%), with only 18.8% being suburban areas.

The majority of the last complex site workers had been on were static/fixed sites (83%), followed by mobile (9.0%), and semi-static (8.0%).

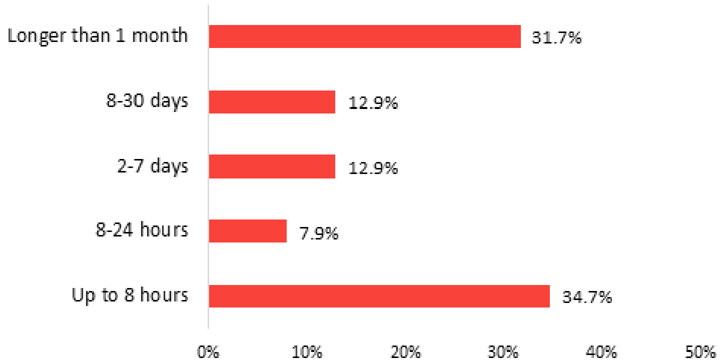
Most sites involved either lane closures or single-lane alternating traffic.

Most of these complex site were managed for less than 8 hours or more than 1 month.

How was traffic managed at the last complex site?



How long was this complex site running for?

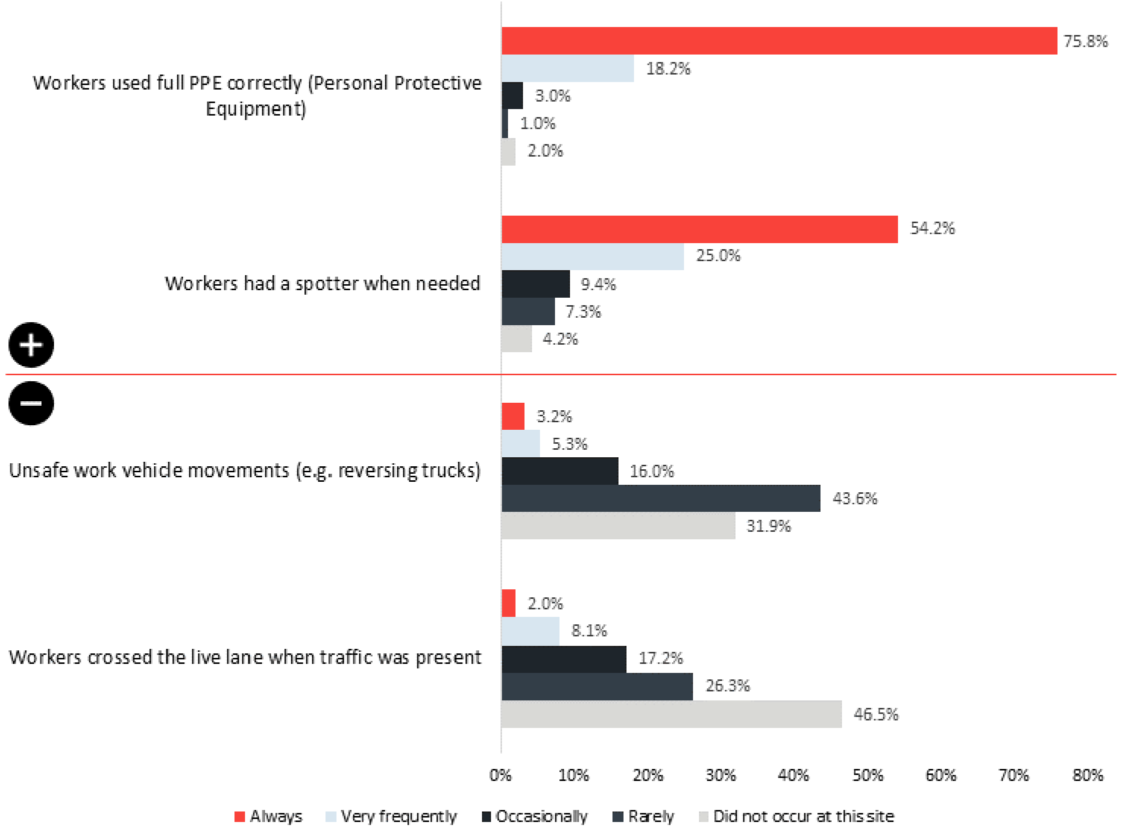


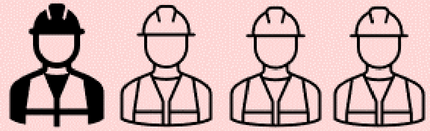
27

n = 101

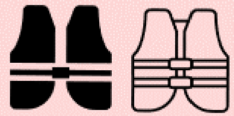
Complex site analysis

Site behaviour

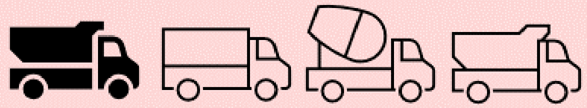




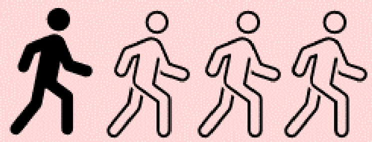
1 in 4 respondents indicated that workers did not always use full PPE.



Only half of workers always have a spotter when needed.



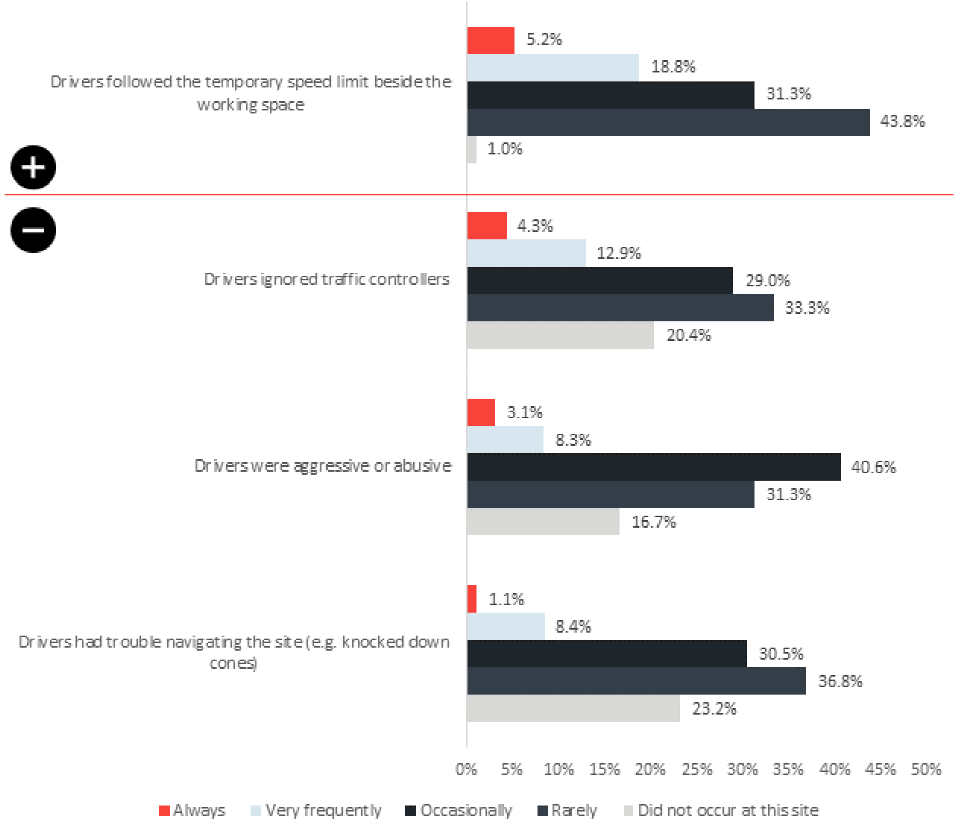
1 in 4 respondents indicated unsafe work vehicle movements occurred at least occasionally.



1 in 4 respondents indicated workers on the site had at least occasionally crossed the live lane when traffic was present.

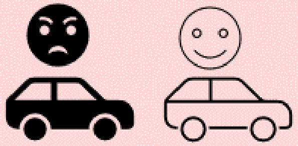
Complex site analysis

Driver related

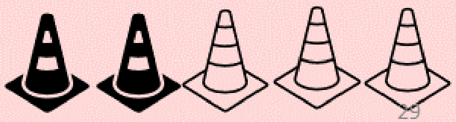


The most common issue involving public drivers was not adhering to the temporary speed limits, followed by drivers ignoring traffic controllers.

Just over half of responses indicated at least occasional abuse or aggression from public drivers.



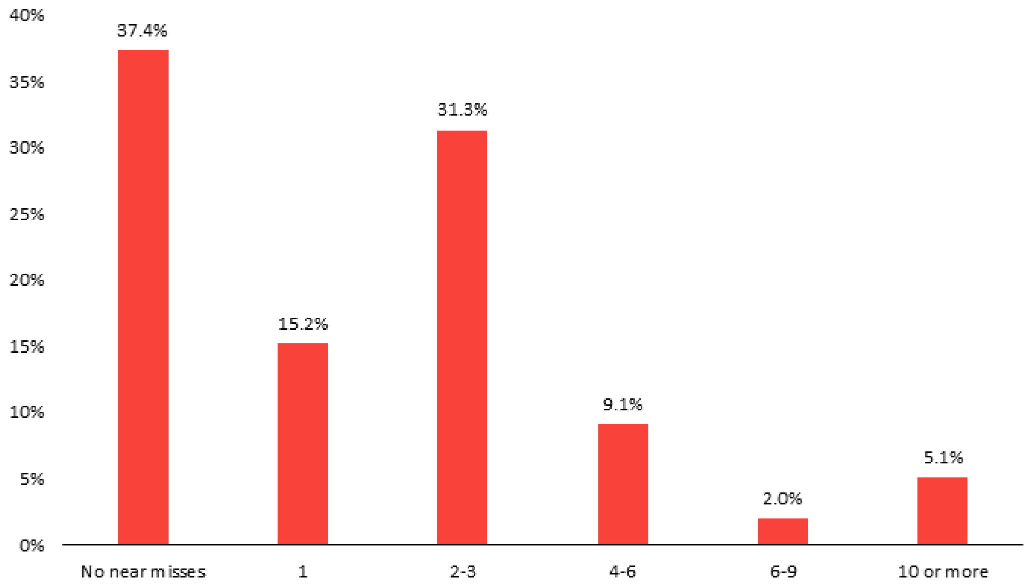
2 in 5 workers reported public drivers had trouble navigating the site at least occasionally.



Complex site analysis

Near misses

The majority of respondents (62.6%) reported observing or hearing about near-miss incidents at the last complex site they worked on, with over half reporting more than one near miss.



30

n = 99

Near misses by site types (complex sites)

Complex site analysis

Sites with **single-lane alternating flow setups** (stop/go with either MTC or portable traffic lights) had the highest rate of near misses.

Sites with **reduced lane width** had the lowest rate of near misses.

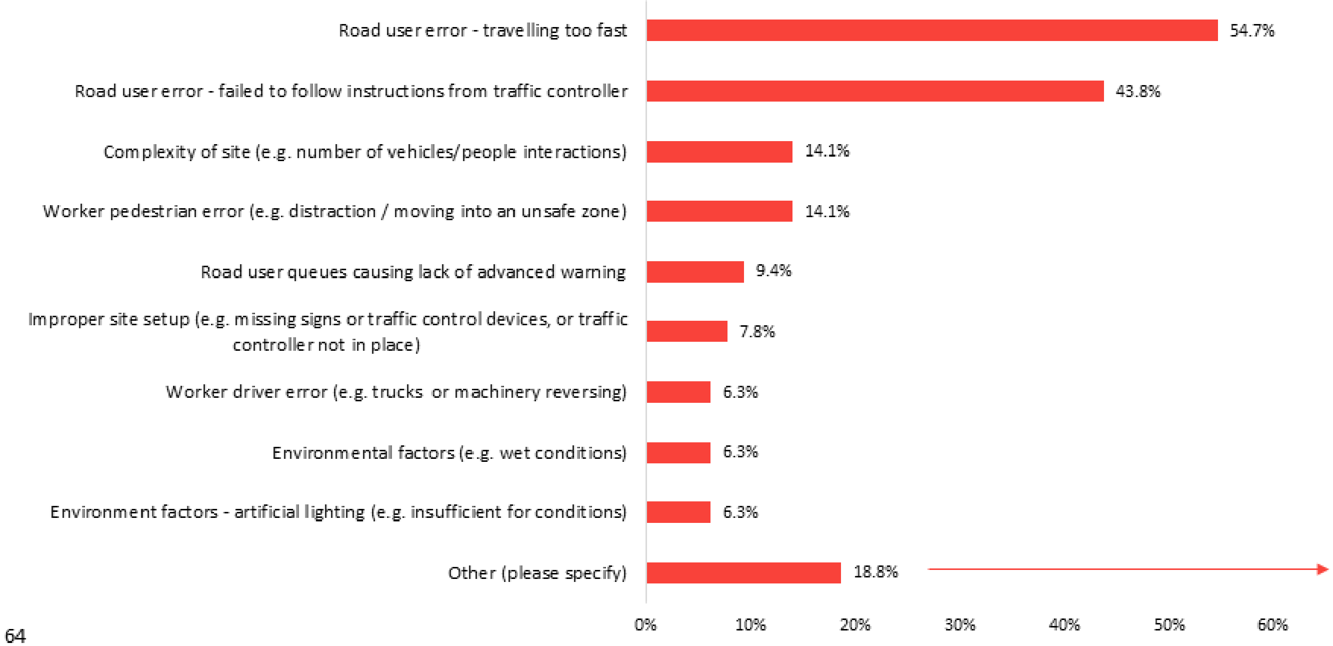
Site type	Proportion of sites with near misses	Number of near misses per site (average)	Number of near misses per day
No lane closures	46%	2.71	0.21
Reduced lane width	50%	2.79	0.09
Lane closures	**77%**	5.51	0.22
Single-lane alternating flow	67%	**7.94**	**0.82**
Full closure	50%	4.02	0.18

Contributing factors

Complex site analysis

The two most selected items related to respondents' perceptions of the main contributing factors were related to road user error.

Over half of the respondents selected 'road user error – travelling too fast' as a main contributing factor.



n = 64

Other factors identified:

"Elimination of risk (road closure) was not approved due to customer impact. Site safety zones (lateral) compromised due to this."

"The site has been up for a while and the site setup was around a corner. Road users complacent and don't think the reduced signs apply."

"Road users not seeing or obeying pre-warning signs"

"Road user inattention"

"Road user error – cyclist turning into oncoming vehicle at intersection."

Complex site analysis

"More cones IS NOT the answer to every problem. They clutter and confuse the site, the public can't see workers with orange safety clothes. We need immediate enforcement of speeders and those abusing staff."

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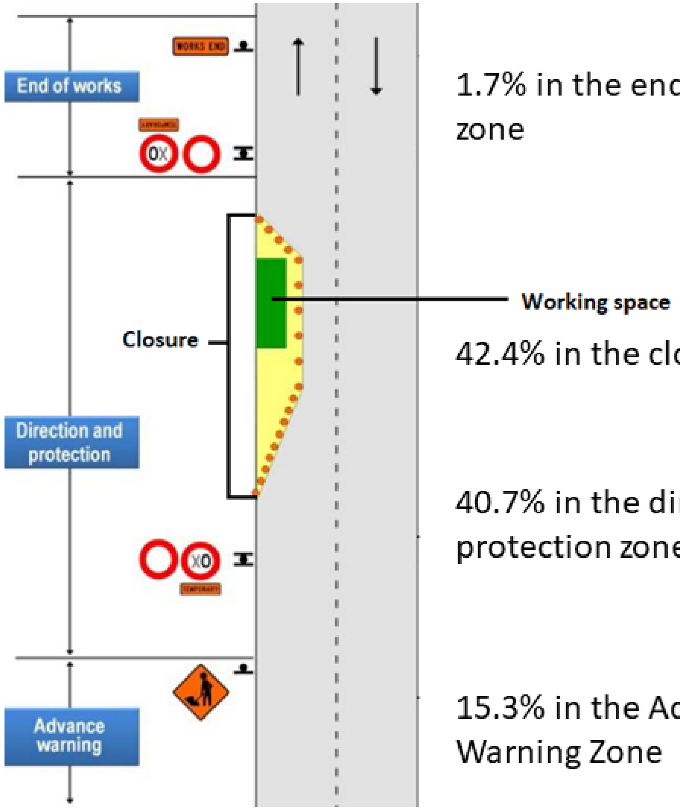
Complex site analysis

Near miss site locations



(n = 59)

	Example serious near misses	Example solutions
1.7% in the end of work zone	"Speeding through TSL 50km, admitted to Police they were doing 80km. Spun out on loose chips. Roads were being swept at the time."	n/a
42.4% in the closure zone	"Lifting a pole off a truck, said pole nearly went into live lane."	"Holding traffic on both ends for a few minutes until he's finished"
40.7% in the direction and protection zone	"Cars speeding through site nearly hitting pedestrians using our temporary crossings…"	"Closed the road or use another type of crossing, e.g. school crossing equipment to stop road users when the public are crossing the road."
15.3% in the Advance Warning Zone	"Road user not reducing speed when coming up to traffic lights. Traffic lights set up around a corner and they had to slam on the brakes quickly."	"More positive traffic management to reduce the traffic width…"

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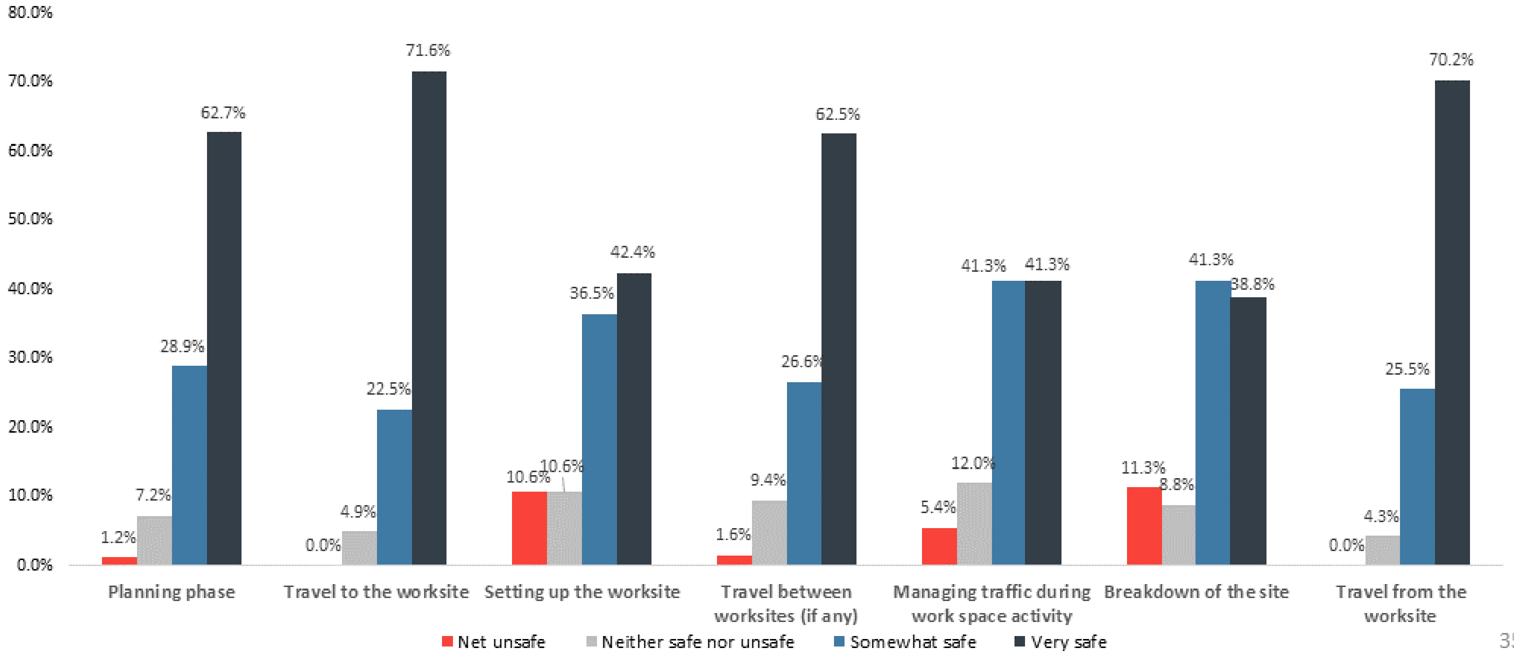
Safety during site stages

Complex site analysis

Respondents largely reported feelings of safety when working on site.

The most noticeable reports of feeling unsafe were in relation to setting up and breaking down of sites.



n = 110

35

Complex site analysis

Who was the most at risk of serious injury?

2 out of 5 respondents stated the public were most at risk during the near miss (of these, pedestrians/cyclists made up 20%).

n = 62

Public Driver
35.5%

Public Cyclist/ Pedestrian
8.1%

Work Zone Worker – Walking
29.%

Temporary Traffic Management Worker – Walking
22.6%

Work Zone Worker – In Vehicle
4.8%

36