AA Research Foundation

MAKING WORK SITES SAFER AND MORE EFFICIENT

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ABBREVIATIONS

AADT	Average Annual Daily Traffic
AWADS	Active Work Zone Awareness Devices
AWIS	Automated Work Zone Information System
DMS	Dynamic Message Sign
DSI	Death and serious injury
FDOT	Florida Department of Transportation
NZTA	New Zealand Transport Authority
MIRi	Measurement of Injury Risk
MoT	Ministry of Transport
PCMS	Portable Changeable Message Signs
PTSD	Portable Traffic Signal Devices
TMAs	Truck Mounted Attenuators
TTM	Temporary Traffic Management
TMP	Temporary Management Plan
VES	Visual Enhancement Systems
VMS	Variable Message Signs

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SUMMARY INSIGHTS

This research comes at a critical time, where disruptive storm and flood events means more roadworks are taking place. Temporary Traffic Management (TTM) closures impact drivers and result in an increase of crashes by about 22%. This study investigated what could be implemented to make work sites safer and more efficient, with a particular focus on lane closures.

There are 71 deaths and serious injuries at TTM worksites every year in New Zealand.

There is a higher proportion of fatal TTM crashes in New Zealand compared with comparable countries.

In NZ we have some innovative techniques and approaches that make work sites safer, and minimise impact on road users:

- We have improved planning that optimises full road closures and saves on TTM costs
- We have better tools to inform road users e.g. Portable VMS to provide dynamic information

However, there is a lack of monitoring culture to collect evidence on what does and doesn't work and how much impact it may have, which limits improvements.

WHAT CAN BE DONE DO TO OPTIMISE TTM AND ENABLE IMPROVED ROAD USER BEHAVIOUR

1. **USE FULL ROAD CLOSURES** outside of peak times, to enable efficiency for road users and workers
2. **BUILD CONFIDENCE IN SIMPLE SITES** by developing an Aotearoa New Zealand specific plan to apply Austroads simple sites guidance and work industry to evaluate and share data on simple setup options
3. **TRIAL** options like average speed cameras, AWADs, and 'End of queue behaviour change' campaigns
4. **FUND PERFORMANCE MONITORING,** including a new rule requiring at least one safety and one efficiency metric for larger works programmes

1 PROJECT BACKGROUND

1.1 INTRODUCTION

This research comes at a critical time, where disruptive storm and flood events means more roadwork is taking place. In addition, cost and the value of traffic management is being closely examined, and the industry is moving to a new way to manage risk. Temporary Traffic Management (TTM) closures impact drivers and result in an increase of crashes. This study will investigate what could be implemented to make work sites safer and more efficient, with a focus on improving driver attention, comprehension and behaviour through work sites.

"We have a whole stack of engineering treatments, but it's the human behavioural thing." (E1)

In New Zealand there are 71 deaths and serious injuries (DSI) at TTM worksites every year (TTMISG, 2024), which accounts for about 2.6% of our national DSI crashes (MoT, 2024). When comparing the proportion of fatalities at work sites (compared to overall fatal road crashes), New Zealand has a higher proportion of fatalities at work sites (2.5%) than other countries like Australia (1.5%) and USA (1.9%; Austroads, 2022; DITRDCSA, 2024; NSC, 2025; NWSIC, 2025).

Lane closures represent the greatest safety risk to TTM workers, impact most on delays for our drivers, and require more temporary traffic management (e.g. Rista et al., 2017; Thomas et al., 2023). Focusing on lane closures, this study investigated what could be implemented to make work sites, and consequently road user behaviours, safer and more efficient.

Lane closures for our purposes include any site where work means a closure of any lane. This includes multi-lane static and mobile lane closures (where drivers engage in a merge or lane shift), as well as single-lane alternating flow sites with stop-go (see Figure 1) or temporary signals (which allow only a single direction of traffic).

Figure 1 Lane closure site with single-lane alternating flow using a manual stop-go control (Source: New Zealand Transport Agency, 2022)

1.2 PURPOSE

The findings of this study will be used to:

- rationalise worksite design
- improve driver understanding and interaction with work sites and
- safely optimise flow and reduce disruption

1.3 METHOD

The research includes:

1) A **best practice review** focusing on safe flow and improved driver understanding of worksite requirements using international and national best practice.
2) **Interviews with key informants**, using 5 national and international experts to discuss interventions that have been trialled or processes that are run differently to understand deeper insights.
3) **Recommendations and Trial Options**: policy, guidance and intervention recommendations applicable to New Zealand, as well as identify next steps to scope any New Zealand trials.

2 BEST PRACTICE REVIEW

2.1 OVERVIEW

The desktop review focussed on safe flow and improved driver understanding from international and national best practice, including:

1) TTM setups that improve flow and reduce disruption (including the recent shift to night work to reduce disruption).
2) Driver behaviour studies at worksites- to understand what information drivers seek at sites, and what elements could improve flow in different driving conditions (with the concept that confusion also causes delay and reduces safety).
3) Identifying how to communicate better quality information about site characteristics to drivers (relevant to site driving behaviour and decision-making).
4) Improving inactive work site procedures (to improve TTM credibility).
5) Examining what technology advancements work for safer nighttime work sites.

The full review can be found in Appendix I.

2.2 SUMMARY

The following points summarise the findings of the best practice review:

TTM Setups

1. TTM Risk: Overall, temporary worksites can increase risk by as much as 22% (relative to typical non-worksite driving conditions), with lane closures increasing risk by 12-22% and lane shifts increasing crash rates by about 40%.
2. Solutions for Speed Management: Excessive speed is a major factor in worksite crashes. Controls that lead to appropriate speeds include speed cameras, real-time speed feedback displays and rumble strips (especially for heavy vehicle speeds).
3. Solutions for Worksite Flow: Include smoother merging behaviour and improved speed harmonisation. In heavier traffic conditions, Early Merge setups improve merge throughput (by about 21%) and Variable Speed Limit signs can adjust speed limits based on conditions and reduce speed variability and improve site throughput (by about 7%).

Figure 2. Example of the joint merge layout (from Wolshon et al., 2012)

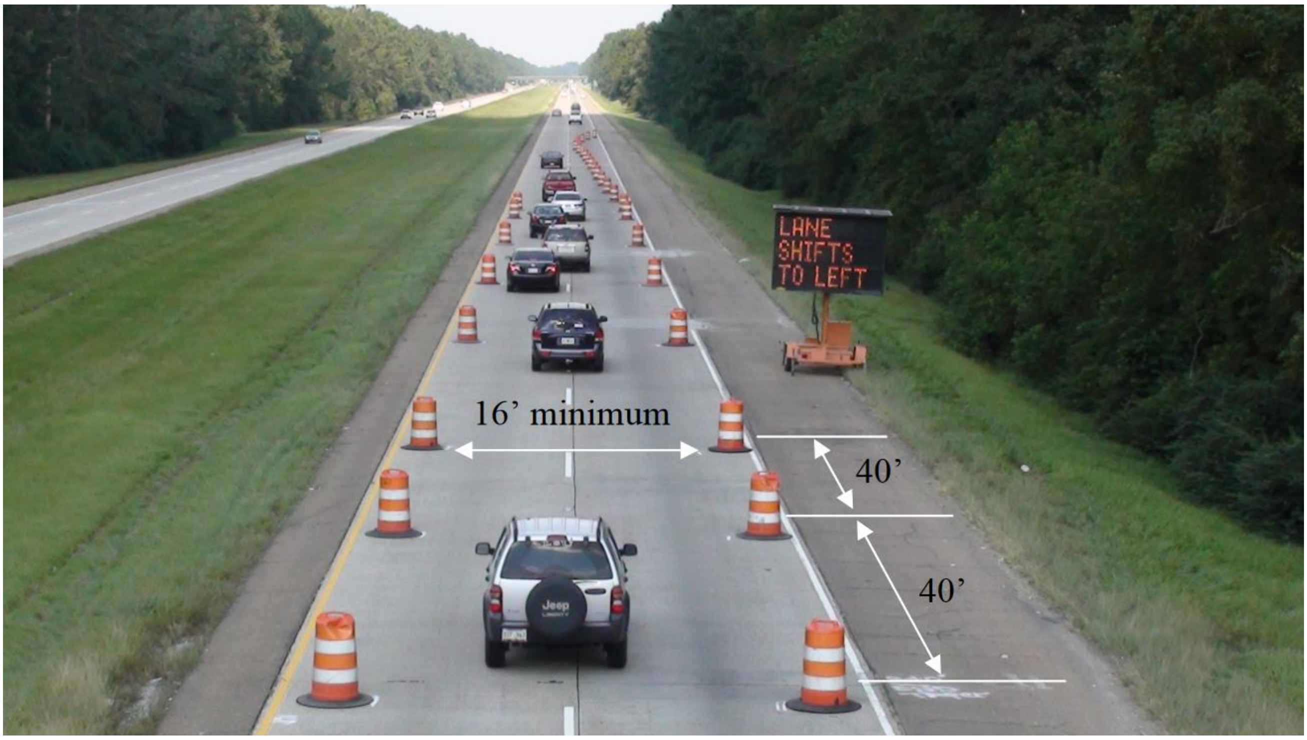
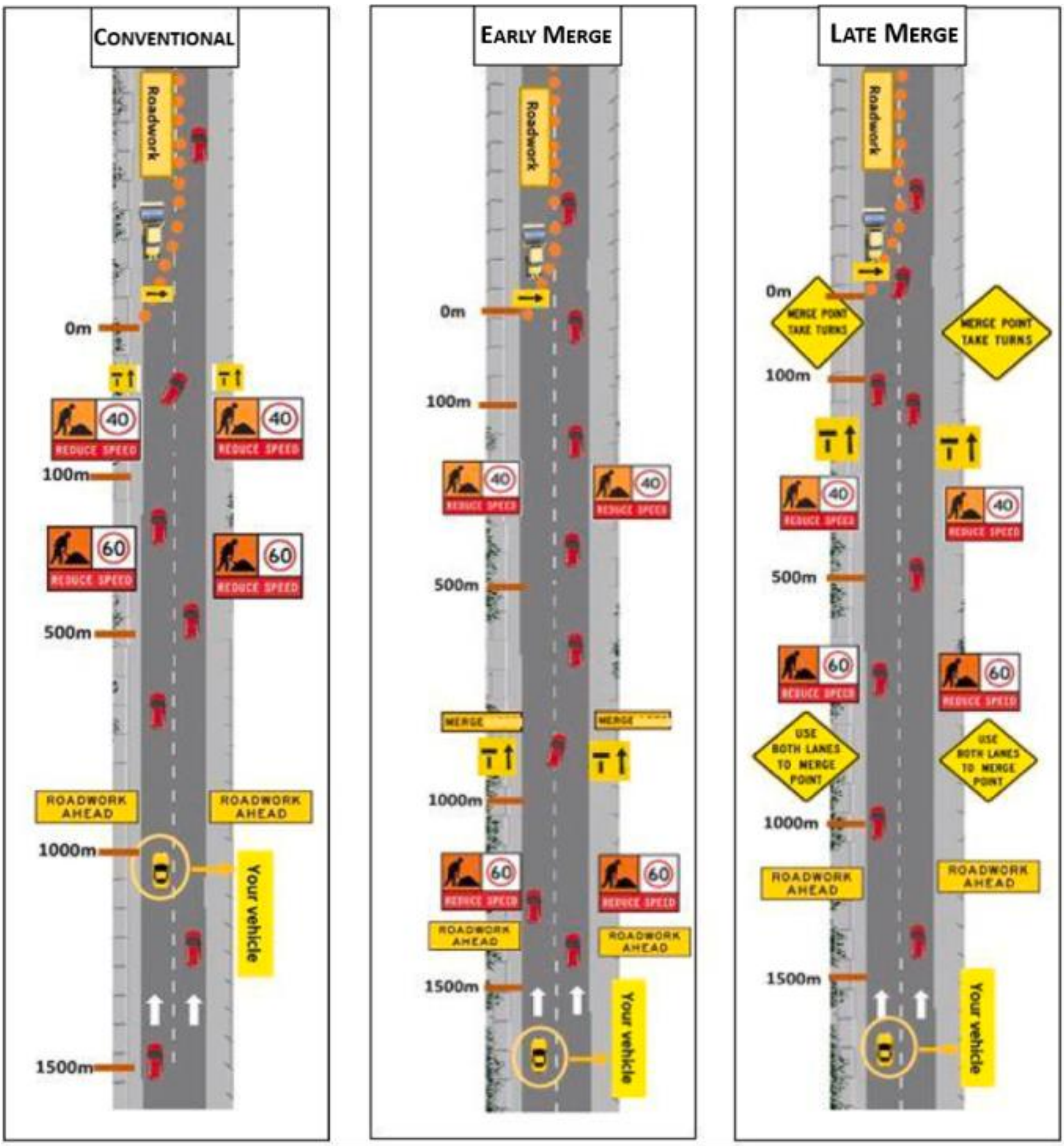


Figure 3. Variable speed limit sign (from Fudala & Fontaine, 2010)

Figure 4. Example Australian setups for a) conventional merging, b) early merging, and c) late merging (Source: Siriwadene, 2024)



Driver Behaviour and Quality Information

1. Failure to detect worksite: Drivers often fail to adapt to changed driving conditions at roadwork approaches, leading to crashes.
2. Signage and Information: Clear signage and information reduce driver confusion and improve compliance. However, drivers do miss static signage, indicating the use of

repeater signs or dynamic lights or signage that captures driver attention is favoured, especially at sites with low sight distance.

3. Solutions for improved driver information: Portable Changeable Message Signs (PCMS) offer dynamic information, and in relation to sign content graphical or simple messages that are most effective in reducing speeds.
4. Worksite avoidance solutions: Information systems, like the Automated Work Zone Information System (AWIS) supports drivers to choose off-peak travel and alternative routes around work sites by showing expected delay times and/or alternative routes reducing peak hour demand by 18% and delays by 44% during peak hour.

Figure 5. Text PCMS (left) and graphic PCMS (right) (from Yong Bai et al., 2011)

Speed Credibility and Inactive Work Sites

1. Driver Perceptions: Drivers are less likely to exceed speed limits when they understand the need for the slower speed (e.g. at active work sites with people working), where the environment feels like a need for a lower speed (e.g. narrower or closer spaced cones, or an unsealed surface), and where they feel that the speeds will be enforced.
2. Speed Credibility: Ensuring speed limits are credible and enforced can prevent erosion of trust in traffic measures and improve overall safety.
3. Active Work Zone Awareness Devices (AWADs) are effective in reducing speeds, provide immediate driver feedback, and act as a tool for enforcement that targets speed at active work sites, highlighting their potential for broader implementation.

Figure 6. Active Work Zone Awareness Devices (AWADs), showing a trailer-mounted setup (from FDOT, 2021)

Technology Advancements

1. Nighttime Work Site Safety: Fatal accidents are significantly higher at night (about 5 times higher), mostly related to public moving through the site, indicating the need for more road closures at night to mitigate exposure to risk and better technology when this cannot be achieved.
2. Technology solutions: Advancements indicate improved safety opportunities, including sequential warning lights, improved PPE visibility, and automation technology to reduce site setup time and exposure.

Figure 7. Sequential warning light (Sun et al., 2012) Figure 8. SwiftGate installation (National Highways, 2022)

3 KEY INFORMANT INTERVIEWS

Interviews were conducted with five key informants to provide deeper insights about opportunities for safer more efficient work sites.

3.1 PURPOSE

The focus of these interviews was to provide deeper insights into:

- Changes to improve safety and optimise the safe flow of vehicles.
- Potential interventions that have shown to be effective.
- Future approaches that should be used for New Zealand and why.

3.2 INFORMANTS INTERVIEWED

Semi-structured interviews were run with five key TTM industry informants from New Zealand, Australia, and the United States (see Table 1). A purposive sampling approach was taken for interviewees, focussing on lessons from novel international approaches to TTM, and detailed knowledge from New Zealand interviewees with in-depth knowledge of existing practices and what is being tried under the new risk-based approach to TTM.

Table 1. Expert interviewee location and summary of experience

Interviewee	Location	Years of TTM experience	Roles or type of experience
E1	Australia	30	• Guidance and standards (including delivery of Austroads guide to TTM) • TTM Planning and Design • TTM Training
E2	Australia	13	• Industry research and evaluation
E3	United States	21	• Research and evaluation
E4	New Zealand	19	• TTM Planning and Design • TTM Training
E5	New Zealand	28	• TTM Planning and Design • TTM Training

3.3 LANE CLOSURE CHALLENGES

Interviewees were asked questions about how well lane closures are managed in terms of safety and traffic flow, including the biggest challenges the industry currently faces.

A key challenge raised by interviewees is the risk of crashes that arise from unexpected queue lengths. It can be difficult to accurately predict queue length during the TTM planning phase. They also raised challenges in driver behaviour, communication of site risks to drivers, inactive work zones and the risk-based approach.

DATA AND EVIDENCE

- Lack of data can lead to an "adding more" approach.

  While there is evidence of innovation, the performance of the changes being made is not clear across New Zealand and Australia. When combined with a risk aversion around taking anything away, this can lead to a process of adding more.

  "There is a significant lack of evidence base in Australasia related to what actually works for the local conditions. People are seeing road work signs, road work zones often, and more often than previous times. At the same time, we are trying to protect our road workers, which of course we should do…To do that what we are trying to do, (is) to put more cones, more signs and then other things" (E1).

TTM SETUPS:

- Crashes due to queue length.

  Especially heavy vehicles running into the end of an unexpected queue. Difficulties were identified in, 1) accurately calculating lane closure queue length in the planning phase, 2) the need to have extra staff on site to change the length of the site (i.e. shift the advanced warning signs), and 3) limitations in the allowance for planning flexibility of site length.

  > *"So I know "when I'm driving along the road and come across the end of the queue, I am bloody nervous. I'm sitting there thinking I am constantly looking in the rear-view mirror. I tend to stop quite a couple of car lengths back from the car in front. Until vehicles have come up behind me, then I'll edge closer" (E1).*

DRIVER BEHAVIOUR AND QUALITY INFORMATION:

- Driver attention and preparation.

  Drivers on autopilot being blind to signs on approach to the work site. A lack of understanding around how we capture driver attention was noted as a key issue by one industry expert:

  > *"We have a whole stack of engineering treatments, but it's the human behavioural thing." (E1)*

The use of cones was indicated as one mechanism to create a visual "tunnel" effect to capture the change in driving environment, where drivers often slow down in narrow environments like tunnels and bridges.

> *"(In NZ) You have a line of cones down the middle of the road and a line of cones at the side of the road. They're 900 mil high. They're bloody big cones. As a driver, it feels like you're driving almost into a tunnel between two walls. We don't do that in Australia. So cars tend to wander around a fair bit more. There's less of that feel that I need to slow down. As well as having a sign at the road 500 metres prior to the traffic control station is having a bunch of cones in a line right next to the edge of the line. Which might just to wake that driver up a little bit more" (E2).*

Drivers need clear and advanced warning of lane closures to prepare themselves for merging. Insufficient or poorly placed signage can lead to last-minute and unsafe merging behaviours.

> *"When there's a lane closure, the danger is that because one of the lanes is going to disappear and the traffic needs to merge, you really want to give people warning ahead of time so they can position themselves." (E3)*

- Low comprehension of work site risks and the need for the work.

Long-term change is needed to make drivers aware of the risks, increasing their understanding of the need for the works, and keeping drivers aware of this. This is necessary to underpin a real shift in behaviours like speed.

SPEED CREDIBILITY AND INACTIVE WORK SITES:

- Speed compliance and the halo effect of enforcement.

The benefit of enforcement is, it is more effective with speed compliance than other physical site controls. However, while enforcement is effective when in use, there is a halo effect where drivers that are outside of the enforcement zone return to typical behaviour.

> *"Yes, enforcement works. But how many places can you do enforcement and for how long?" (E2)*

Enforcement does not address long-term reduction in negative behaviour. It only works when drivers believe they are going to be caught.

> *"Enforcement is a spot fix. It does not have a long-lasting effect." (E2)*

> *"Our research found that the presence of law enforcement had immediate effectiveness to reduce speed. But when they disappear or are hiding, people don't see them, and that effectiveness drops." (E3)*

- Challenges of inactive work zones.

  Drivers often exceed speed limits in work zones, especially when no workers are visibly present.

  > *"People complain about [lower speed limits at inactive work zones], saying, a lot of the time, there's nobody there. There's no work zone activity, but you put a lower speed limit there — it's not reasonable for us to follow that." (E3)*

POLICY AND GUIDANCE:

- Risk around working differently.

  There is fear of moving to a risk-based approach and moving away from fixed guidance, including fear of being at fault if trialling or moving to a different approach.

  > *"The immediate barriers is the fear of what risk-based actually is…a lot of people haven't leaned into this sufficiently enough yet to understand and then try to abate their fear." (E5)*

  There is a fear of prosecution, as the contractor or lead contractor is the one that is prosecuted, so they also perceive themselves as the "gatekeeper of risk". Therefore, change is difficult.

3.4 POTENTIAL LANE CLOSURE SOLUTIONS

When asked, "what is the ONE thing we should be doing now?" experts responded with the following key actions.

TTM SETUPS

- Better forward planning (E4).

Forward planning to group all work along a route together.

> *"Grouping work together to increase the work to TTM ratio is what we need to do." (E4)*

For example, if doing a reseal for 1 km one year and the next 1 km in the following year, group the work together and looking at other utilities underground services (water, power, data) and road infrastructure (e.g. signage) that must happen on the same route. At present, some key limitations to overcome are:

- visibility of work that is happening.
- scope changes in work (e.g. delays to planned work due to reductions to planned maintenance budgets is not uncommon); and
- public acceptance.

> *"There is a need for public acceptance. Acceptance of a bigger impact, but over a shorter timeline." (E4)*

DRIVER BEHAVIOUR AND QUALITY INFORMATION

- Driver behaviour research (E1).

There is a lack of evidence behind the controls used, especially around how they are affecting driver attention and safe speed behaviour:

> *"Quite frankly, we're all stabbing in the dark in terms of how do we really get to that long distance trucker who's been on the road for 10 hours of the day and is right at the end of their current shift. What more should we be doing? At the moment I feel like, oh, here's a problem. Let's just add some more to it." (E1)*

> *"The main element in this process is driver behaviour. The ideal solution is to make drivers aware of the risks. It would need to be a combination of Social, Driving culture, Driver training, in combination with consistency in temporary traffic controls." (E1)*

Similarly, controls around speed may be limited if driver comprehension is not monitored, based on recent survey work in Australia one expert reported:

> *"60% of drivers believe that road work speed limits are advisory only. They're not mandatory. Whereas they are the same speed signs as we use for permanent signs." (E1)*

- Shifting risk perceptions.

Perception of risk is a key element that influences driver behaviour. A key insight around how people interpret risk at work sites that is quite telling is where drivers will adapt their behaviour to protect their vehicle from damage (e.g. slow down for loose chip), but do not prioritise harm to themselves or others:

> *"Drivers are more likely to slow down if they see a risk to their vehicles, more so than a serious risk to themselves." (E1)*

- Improving driver comprehension of work sites (E2).

This includes consideration of better integration into driver training for the next generation as well as ongoing social campaigns to shift negative attitudes and help drivers understand the why behind site setups:

> *"You should see work zones as a workplace…there are humans who are working. They need to have breaks, right?". (E2)*

- Providing advanced notice through clear and strategic signage (E3).

Effectively informing drivers in advance of lane closures can help prepare for merging lanes and navigating safely. This includes clear and strategically placed signage to give drivers sufficient notice, particularly when lanes are disappearing. Simple changes such as installing speed limit signs on both sides of the road for increased visibility, along with the use of technology such as Automated Work Zone Awareness Devices (AWADs) and dynamic message signs can enhance driver awareness and compliance. This reduces the likelihood of risky last-minute actions such as abrupt lane changes, improving traffic flow and safety.

"Signage is crucial for the driver, especially when traffic is heavier. When traffic is heavy, the available capacity to merge is not much." (E3)

"You need to give [drivers] no reason to say: 'I didn't see [the signage]'." (E3)

SPEED CREDIBILITY AND INACTIVE WORK SITES

- Ghost sites and speed credibility (E1).

Ghost sites is another issue that was raised around speed credibility. A key issue identified was the cost. For example, on a multi-day site it is cheaper to set up, leave it until the end of work and then pick up the equipment again. One solution discussed was the use of a dedicated surveillance and audit team to inspect sites. Another was just to run full road closures.

"The biggest problem we've got is that Contractors don't want to pay for someone to have to go out and cover or move signs. And that goes for the speed limits as well. They leave the speed limits up inappropriately. Some work may be better off just to close up the road and get it done in a you know, in a very quick manner." (E1).

POLICY AND GUIDANCE

- Greater flexibility in work site planning (E5).

At present, there are generic plans in place that are easier to implement but may not be optimised to the type of work, location or conditions. On the other end of the spectrum, there are site-specific plans that are optimised but require more approvals, including a full Traffic Management Plan (TMP) process. Anything in the middle has a higher perceived risk (e.g. around legal implications if there was a crash).

"We need greater support for something in the middle...providing a level of supervision and information to our people....so that improves the way we plan and our responsiveness to lane closures." (E5)

"We need to find the balance of risk around what is the best traffic management arrangement. How much risk am I actually mitigating by setting up a complex site, you're talking an extended length of time that workers are exposed during the set up and during the pack up." (E1)

3.5 FUTURE APPROACHES TO IMPLEMENT

To ensure practicable implementation, when interviewees were asked about a range of opportunities to improve safety and flow through work sites this was split into Simple and Complex work site solutions. Based on the literature review findings, the examples below were tested with interviewees in addition to any others they had discussed (see Figure 9).

Figure 9. Potential trial options discussed with interviewees

3.5.1 SIMPLE SITES TO IMPROVE EFFICIENCY

Simple work sites can be short-term or low impact, including vegetation, sign or pothole management in low speed, low traffic conditions.

Austroads, AGTTM Part 5 provides an entire guide on Short-Term Low Impact worksites (Austroads, 2021), which covers work carried out without the use of a fully protected static or mobile worksite. It does not require speed limit changes, lane shifts (tapers), traffic controllers, aftercare signs or unattended worksites, or redirecting pedestrians. It does include work that has minimal equipment and workers, short duration, a frequently changing work area, or work located sufficiently clear of traffic.

Type of work includes:

- Works protected by a specialist vehicle (e.g. placement of temporary signs).
- Working in gaps between traffic (e.g. removing debris).
- Short-term work (e.g. pavement investigation).
- Working on medians, verges or footpaths (e.g. edge marker post repair, footpath repair).
- Frequently changing work area (outside traffic lane, e.g. vegetation management, street light maintenance).
- Constantly moving works within traffic lane (e.g. mobile inspections, grading).

Australasian experts all discussed examples of these including rolling blocks and a potential future opportunity for investigation into self-explaining roads at TTM sites, which are discussed below.

CASE STUDY: ROLLING BLOCKS

Where work vehicles move through to block a single lane for short durations (like 5 mins). This is an opportunity where traditionally the time to set up may be longer than the time it takes to do the work.

One example of this is a sign pole replacement where TTM vehicles block a single lane while workers remove a broken sign taking approximately 5 minutes. The new pole is added to the sign at an off-road location taking 30 minutes during which there is no TTM in place. The TTM vehicles then return to block the lane while sign is reinstalled.

Benefits:

- Reduced total impact time blocking live lane at site from 150 mins to 10 mins.
- Reduced time and cost of TTM overall.
- Larger wait times on a small number of vehicles.

Risks:

- Providing an adequate understanding of delay and the need to wait by members of the public.
- Overtaking the work vehicles if drivers do not comprehend. This is a risk to both workers and / or public using the alternative lane.

CASE STUDY: PORTABLE TRAFFIC SIGNAL DEVICES (PTSD)

One interviewee (E1) highlighted the increase in use of traffic signals over manual control. In Queensland, Australia, there has been a significant move away from manual traffic control to the use of traffic signals at most sites. This approach protects traffic controllers by reducing their exposure to traffic risks. However, there are challenges with ensuring traffic controllers stand in the correct place. They identified that more work is needed to improve the visibility of traffic signals, especially in rural areas.

> *"I think there's more work that can be done to improve the visibility of those devices. Because particularly out in the rural area where you're driving along and suddenly got this one little signal there."(E1)*

A New Zealand Interviewee (E5) discussed Portable traffic signal devices (PTSD) (such as E-Stop) being increasingly used in New Zealand to protect workers by moving them a safe distance from moving vehicles where they can control the flow of traffic. There is the potential to improve on this using vehicle-actuated operation that allows the signals to automatically respond to vehicle cues and adjust the phase lengths accordingly (NZTA, 2024a).

Benefit:

- TTM worker safety (only exposed to risk when setting up and taking down the PTSD).
- Reduced queues, where the light timing could reduce delay through automated response to vehicle queues.

Risks:

- A risk associated with not having an observer on site is where drivers choose to or unintentionally run the red light. When this occurs with an observer, they can communicate that there has been a breach.

POTENTIAL OPPORTUNITIES: SELF EXPLAINING ROADS AND TTM

Self-Explaining Roads are those that provide a predictable environment that matches user expectations and consequently encourages safer, predictable speeds and movements. An example is reducing cone spacings so drivers will naturally feel they are going faster and reduce speed (see Section 2.2). Interviewees discussed the balance of TTM setup time and driver awareness of the road environment.

> *"One of the options I want to explore is a simplified setup. And basically, the theory I'm working on is where the TTM to work ratio is really out of whack, can I shrink the TTM*

while still giving me enough control to get people past me through a single lane safely?" (E4)

"Simplified setups and almost moving to a self-explaining roads type approach is something we definitely want to explore quite a bit more." (E4)

"The use of speed limits has become far more constrained, but it's led to sites which now makes sense to the driver. So that they feel that self-compliance is the right thing to do. The vast majority of drivers will do the right thing when it makes sense." (E2)

Specific mentions included that:

- A lit up TTM vehicle with flashing lights may not need to have road cones around it for identification.
- When driving on a new chip seal it is evident that it is loose so drivers will reduce speed.

3.5.2 COMPLEX WORK SITES

Complex work sites are those where something at the location requires consideration of the risks more than usual, such as limited space or view, or difficult traffic decisions.

3.5.2.1 EXPERT VIEW: FULL ROAD CLOSURES

Full road closures remove interactions between drivers and work sites. Planned well and with good public communication they make it safer and less disruptive. One interviewee (E4) discussed the need for public acceptance of more impact over a shorter timeline. Full closures were ranked highly by all experts, including discussion of Remutaka Hill closures (see Figure 10 and Section 4.2).

Figure 10. SH2 Remutaka Hill Full Closure (Source: NZTA)

The SH1 Urban Motorway had overnight road closures run by the Wellington Transport Alliance (NZTA, 2024b). Over a 3-week period this was found to reduce:

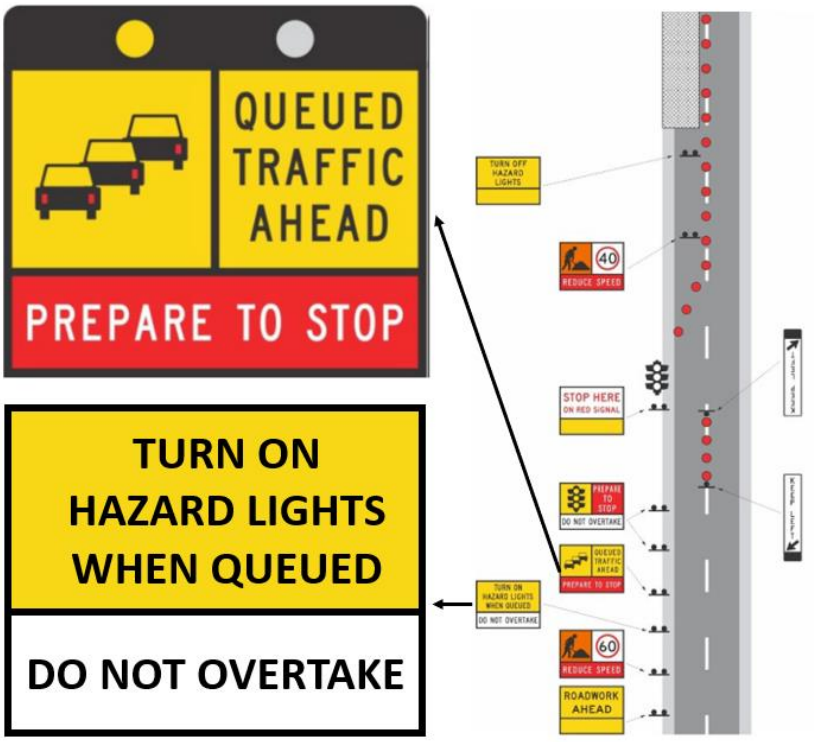
- TTM cost by 40%
- TTM tasks from 68 to 15
- Exposure of high-risk worker activity (by 125 hours)

3.5.2.2 EXPERT VIEW: END-OF-QUEUE RISK CONTROL MEASURES

Queensland guidance (DTMR, 2023) outlines a range of controls, from Variable Message Signs (VMS) to flashing lights on signs warning of queues ahead (see Figure 11).

One interviewee (E3) identified a particularly efficient option involves the driver using their hazard lights if they are the last vehicle in queue. The guide notes that this is acceptable use of hazard lights as it meets the following conditions. That the vehicle is either stopped or slow-moving such that it is “obstructing, or is likely to obstruct, the path of other vehicles or pedestrians”. However, no published studies were identified that have examined the effectiveness of this approach under queued conditions.

Figure 11. Example of end of queue signage interventions (Source: DTMR, 2023)



3.5.2.3 EXPERT VIEW: EARLY MERGE TTM SETUPS

Based on experience in Australian trials, one interviewee (E2) discussed the mixed findings with early merge setups (see also Section 2.2). Early Merge Setups were discussed extensively in the interview, highlighting their potential benefits and challenges. The conversation covered various aspects, including driver preferences, efficiency, and the need for further studies.

Driver Preferences:

- Early merge setups are generally preferred by certain groups of drivers, such as females and experienced drivers.
- Late merges can cause anxiety among drivers who fear not being let in at the merge point or being perceived negatively by other drivers.

Efficiency:

- Some studies suggest early merges are slightly more efficient, but this conclusion is not solid due to heterogeneity in study results.

  "Some studies found late merge is more efficient than early merge. Some found the early merge more efficient... there is no clear consensus in the literature about this."

Need for Further Studies:

"There is a significant lack of field studies."

- More field studies are needed to confidently determine the efficiency of early merge setups (especially examining hourly volume data, as opposed to Average Annual Daily Traffic (AADT)).
- A key challenge is that the correct merge behaviour (for safety and efficiency) is dependent on-site conditions, especially traffic density, and different drivers' preferences and experiences.

CASE STUDY (FLORIDA, UNITED STATES): ACTIVE WORK SITE DIFFERENTIATION USING AWADS

As presented in the literature review (see 6.3) Active Work Zone Awareness Devices (AWADs) are designed to alert drivers when workers are present by using flashing lights. In addition, they also provide the driver their current speed and warn them that they may face a double traffic fine if caught speeding when the work zone is active.

Our interview with one of the authors of a Florida Department of Transportation (FDOT) study on the use of AWADs discussed how these devices have been effectively used. AWADs alone were found to reduce risky driver behaviours; combined with the visible presence of law enforcement (issuing fines) this effect was even more pronounced. AWADs help build trust by only being activated when workers are on site, helping to alleviate driver scepticism about speed limits in inactive zones.

Benefits:

- Compliant vehicle speeds, improved early lane changes, and decreased sudden braking.
- Improved driver understanding of active vs inactive work sites.

Opportunities to maximise the benefits:

- Consistency and driver understanding: Recommend that AWADs become part of the design process as a tool to improve consistency from a driver perspective. At this stage, Florida does not yet require the use of AWADs in work zones, however, this would lead to a consistent approach which drivers could rely on to better understand and adjust their driving based on work zone conditions.
- Speed enforcement: Trials of AWADs relied on police presence when fines were being issued. Some other jurisdictions in the United States use speed cameras at work zones, however this is not yet an option in Florida. Policy support would be required for double fines to be actionable and therefore effective.

Risks

- One risk of using AWADs is that they inadvertently left active when a work zone is unattended, potentially leading to driver distrust and non-compliance. Under the trial conditions they were turned on and off manually.

"When workers are not there, you turn them [AWADs] off. You don't want it on when nobody is there as you start to lose trust." (E3)

4 SUMMARY OF FINDINGS

The purpose of this study was to:

- Rationalise worksite design.
- Identify opportunities to safely optimise flow and reduce disruption.
- Identify opportunities to improve driver understanding and interaction with work sites; and
- Make recommendations for trials or future work.

Overall, there are four key areas that would optimise TTM and enable improved road user behaviours.

1. **Use full road closures** outside of peak times, to enable efficiency and safety for road users, and save costs on TTM setups.
2. **Build confidence in simple sites** by developing an Aotearoa New Zealand specific plan to apply Austroads simple sites guidance and work industry to evaluate and share data on simple setup options. Simple sites can reduce exposure to work and improve efficiency.
3. **Trial** policy-supported options like:
   - **Average speed cameras,** to improve speed harmony, efficient flow and compliance.
   - **AWADs,** to improve driver attention and understanding and safer speeds.
   - **'End of queue behaviour change'** campaigns as a low-cost way to increase attention to work sites through use of hazard lights.
4. **Fund performance monitoring**, including a new rule requiring at least **one safety** and **one efficiency metric** for larger works programmes or innovative trials.

More detailed discussion follows, including more specific recommendations.

4.1 WHAT IS THE VALUE OF TTM? RATIONALISING EXISTING WORKSITE DESIGN

The value of TTM is not well understood. While adding TTM equipment to a site can often improve safety and efficiency, this is not always the case. There is a balance to strike between a layout that is too complex, which prolongs setup time potentially putting road workers in greater danger, and one that is too simplistic, failing to provide drivers with adequate information. There is a need to design sites that are:

> *"Self-explaining and use only controls that make it better" (personal communication, Dave Tilton, 2024).*

TTM adds value where it credibly eliminates risk exposure, improves driver comprehension and promotes predictable driver behaviour, improves speed compliance, and improves traffic flow. In a desktop analysis, Frith (2016) found that where the cost of TTM was about 10% of the overall roadworks cost, this aligned with conceivable safety benefits.

4.2 WHAT ARE WE DOING WELL? POSITIVE ADVANCEMENTS

There are several areas identified in the literature where experts view that we are already adopting new ways of working, especially in the planning phase, but also around cost-effective technology. The more sophisticated planning and technology use case studies could be communicated more widely, to improve both driver understanding of the need for the work and the methods being used to reduce disruption on the network.

IMPROVED PLANNING: OPTIMISING FULL CLOSURES

> *"There is a need for public acceptance. Acceptance of a bigger impact, but over a shorter timeline." (E4)*

At the planning stage, New Zealand is increasingly adopting smarter use of full site closures around high-impact work. For example, full closure of the State Highway 2 Remutaka Hill on a weekend. The benefit of this approach is that it is more efficient, with the ability to finish work that is the equivalent of multiple lane closures. It can often be achieved outside of typical commuting hours, further improving efficiency through reduced exposure to work sites. More night work has already been occurring to limit disruption, but with lane closures rather than full closures. However, the issue is that for the fewer vehicles that move through the site there is greater risk of a crash at night (Arditi et al., 2007). The full closure approach overcomes the increased crash rate at night issue by restricting public access through the site. Full closures can also reduce TTM setup costs, with one example showing a 40% reduction in costs (NZTA 2024b).

A key enabler of this approach is public acceptance and understanding. Understanding why this is occurring (i.e. the benefits), the fact that there may be a larger impact, but on fewer users, and that with good travel planning this impact could be avoided by most road users.

BETTER TOOLS TO IMPROVE ROAD USER UNDERSTANDING: PORTABLE VMS

In New Zealand we could make better use of Variable Message Signs (VMS). VMS provide better opportunities to inform road users about upcoming site conditions that improves driver comprehension (e.g. with the use of icons). Dynamic information has a benefit to drivers in its ability to capture attention (e.g. including flashing lights) and can be altered without workers having to change signage by entering traffic lane to swap signage. Where truck-mounted signage is used there is more flexibility compared with trailer mounted systems.

4.3 WHERE ARE THE OPPORTUNITIES?

The following outlines opportunities in three main areas:

1. Reducing exposure to work sites through Simple Setups (Austroads, 2021).
2. Raising driver attention and understanding of sites through Active work site signage (AWADs) and an End of Queue Behaviour Change Campaign.

3. Improved merge and speed behaviours, with a focus on more consistent driver behaviour.

LOWER IMPACT ON DRIVERS THROUGH SIMPLE SETUPS

Short-Term Low Impact worksite guidance exists for Australia (Austroads, 2021), where certain types of work are being set up with no change in the speed environment, or with minimal delays to the driving public. Similar trials are occurring in New Zealand where time blocking a lane is limited (e.g. rolling blocks) leading to an overall reduction in risk and delay to motorists. However, the uptake of these procedures within industry appears to be as case studies as opposed to standard practice. A large barrier according to New Zealand industry experts is an aversion to the risk if something went wrong. This could in part be due to a transition period as we move from prescriptive guidance to a more risk-based approach to TTM (Thomas et al., 2023). The Queensland Government (DTMR, 2024) has delivered their own version of the Austroads guide for their state. A similar adaptation could be done for New Zealand conditions, TTM roles, and approved tools to make these efficient approaches more widely used. Similarly, better data to provide confidence these setups are working would also build confidence (see also Section 4).

RAISING DRIVER ATTENTION AT ACTIVE WORK SITES

The AWADs system was demonstrated as the best of the active work site tools. It attracted driver attention, provided interactive feedback to the driver including their speed, confirmed to the driver when workers were on site, and enforced speed compliance, including double fines when the site was active. This approach would leverage both intrinsic motivations (to keep our workers safe) and extrinsic motivations (not to be fined). As TTM sites become more digitally integrated, the data on active sites could provide additional information around TTM planning and auditing of ghost sites, building trust and raising speed credibility with the driving public. Other options around ghost sites included better auditing of sites and doing full closures (reducing the number of shifts between active and inactive sites).

END OF QUEUE BEHAVIOUR CHANGE CAMPAIGN

Drivers turning on their hazard lights when queued cleverly uses existing vehicle technology and provides earlier warning of a need to slow down when approaching a worksite. This approach is being applied elsewhere (DTMR, 2023), but there is no identified evaluation of its success. This supports locations with horizontal and downhill curvature and supports drivers of heavy vehicles and drivers who are less alert (e.g. distracted, medicated, intoxicated or fatigued). This would be a low-cost approach, simply requiring a behaviour change campaign and temporary use of signs at work sites while the behaviour was embedded. This would reduce exposure to TTM staff having to manually move signs to extend the site in future. Drivers would need to know clearly that they are allowed to do this and when to use and turn off hazard lights.

EARLY MERGE BEHAVIOUR TO IMPROVE FLOW

There is evidence from some studies that Early Merge setups provide an opportunity to improve vehicle flow through a site by about 21% in high traffic volume sites. This could extend to lower volume sites, but only when driver compliance with early merges is high (over 80%). Early merges also have the benefit of improved clarity on when to merge and can reduce driver anxiety around having to merge late in traffic. This is especially relevant in New Zealand, where both novice and older drivers have anxiety when they drive (Thomas et al., 2024; Thomas & Thomas, 2022). Our interview with one of the leading experts calls for more real-world data to be collected to understanding merging behaviour, including the enablers of more consistent behaviour.

SPEED COMPLIANCE BEHAVIOUR

Average speed cameras provide the best opportunity for a combination of safety (speed compliance) and efficiency (speed harmonisation) for more complex worksites. Once implemented and understood by the driving population they also produce fewer tickets than the more traditional temporary or fixed speed cameras (which can capture unintentional speeding events). Where speeds can be reliably maintained, opportunities to further optimise work sites could be examined, lowering the overall cost of TTM.

4.4 DATA DRIVEN WORK SITE PERFORMANCE IS MISSING

"There is a lack of evidence around how the available controls affect driver behaviour."

The TTM industry is not lacking in innovation, but it is lacking a mature monitoring approach and data. This is evident in the many trials being run, but limited evidence coming out of trials. Especially lacking is data on work site efficiency.

WHAT TO MEASURE?

Better worksite data is needed around:

- Site efficiency: Throughput of vehicles per hour.
- Safety: Including speed compliance, speed harmony (less speed variation leads to safety and improved flow), and better near miss data.

BENEFITS

Benefits of data-driven work site performance include:

- Provides the evidence to move beyond trials and into new best practice.
- Smarter worksite approaches are funded and used because their value is understood.
- Delivery of consistency and lower delays for road users.
- Ability to communicate the success of these approaches back to our road users.
- Increased public and worker confidence in setups.

HOW TO ENABLE THIS?

Technology to monitor speed and flow of vehicles is becoming more cost-effective. However, there are no incentives to monitor.

A new rule introduced in the US includes that at least one safety and one mobility performance measure must be identified for work site programmes, with encouragement to use as many as needed, with the flexibility to choose the metrics that are best suited to the type and scale of work.[1] The US monitoring maturity is high, as they appear to be leading the world in the amount of properly evaluated trials.

[1] Federal Register :: Work Zone Safety and Mobility and Temporary Traffic Control Devices

Boldly applying a similar rule in New Zealand would enable high-value worksites that work for users. Providing mechanisms to access monitoring equipment, expertise to promote capability building, and funding would support the success of such a rule. Around practical implementation, applying this to large work programmes and trials, including trials of simple site setups.

5 RECOMMENDATIONS

Planning and guidance recommendations include:

- Deliver risk-based planning where Full Closures and Simplified Setups are standard practice, including:
  - Using techniques such as requiring a rationale to "opt out" of these approaches.
  - Using Full Closures outside of peak times, to replace higher impact lane closure and lane shift work site setups (especially at complex or longer-term worksites).
  - Using Simplified Setups following best practice evidence and guidance (e.g. from New Zealand case studies and Austroads Short-Term Low Impact worksite guidance)
- Develop an Aotearoa New Zealand activation plan for application of Austroads guidance for Short-Term Low Impact worksites in the NZ context (similar to the process applied in Queensland) to support uptake of the risk-based approach.
- Enable and support more interactive messaging (over static signage) to improve driver attention, comprehension and appropriate behaviour through worksites (especially vehicle-based VMS).

Trial and data policy recommendations include:

- Work with relevant agencies to use and trial options that require support around policy or enforcement, including Average Speed Cameras, AWADs and use of Hazard Lights.
- Work with industry to evaluate and share data for simple setups options in Aotearoa New Zealand, including early merges (to improve flow and reduce merge anxiety), rolling blocks, and Short-Term Low Impact worksites.
- Identify, test and implement new solutions to improve TTM safety at night (particularly for workers around fatigue and visibility).
- Introduce a new rule that at least one safety and one efficiency metric be used for larger works programmes and any trials (following the US model for performance monitoring of TTM).
- Introduce TTM evaluation indicators and funding opportunities (e.g. embedded in contracting or grants) to enable appropriate performance monitoring.

6 REFERENCES

Abraham, D., Spadaccini, J., Burgess, B., Miller, L., & Valentin, V. (2007). *Evaluating and Ensuring Safety of Nighttime Construction and Maintenance Activities*. School of Civil Engineering, Purdue University.

Allpress, J. A., & Leland Jr, L. S. (2010). Reducing traffic speed within roadwork sites using obtrusive perceptual countermeasures. *Accident Analysis & Prevention*, *42*(2), 377-383.

Arditi, D., Lee, D.-E., & Polat, G. (2007). Fatal accidents in nighttime vs. Daytime highway construction work zones. *Journal of Safety Research*, *38*(4), 399–405. https://doi.org/10.1016/j.jsr.2007.04.001

Austroads (2022). Annual Report 2021-22: Solving problems for a sustainable future. Retrieved from: https://austroads.gov.au/__data/assets/pdf_file/0037/529579/AP-C20-22_Austroads_Annual_Report_2021-2022.pdf

Bai, Y., Huang, Y., Schrock, S. D., & Li, Y. (2011). *Determining the Effectiveness of Graphic-aided Dynamic Message Signs in Work Zones*. The University of Kansas.

Benekohal, R. F., Hajbabaie, A., Medina, J. C., & Wang, M. (2010). *Speed Photo-Radar Enforcement Evaluation in Illinois Work Zones*. Illinois Center for Transportation.

Brewer, M. A., Pesti, G., & Schneider, W. (2006). Improving Compliance with Work Zone Speed Limits: Effectiveness of Selected Devices. *Transportation Research Record: Journal of the Transportation Research Board*, *1948*(1), 67–76. https://doi.org/10.1177/0361198106194800108

Chevron Traffic Management. (2021). *Using digital technology to enhance traditional traffic management provision*.

Consolazio, G. R., Chung, J. H., & Gurley, K. R. (2003). Impact simulation and full scale crash testing of a low profile concrete work zone barrier. *Computers & Structures*, *81*(13), 1359–1374. https://doi.org/10.1016/s0045-7949(03)00058-0

Costello, S., & Goluchowski, M. (2006). Improving Safety at Mobile Road Work Zones through a Study of Driver Reaction to Visual Stimuli. *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice*, *15*(4).

Debnath, A. K., Blackman, R., & Haworth, N. (2012, September). *A review of the effectiveness of speed control measures in roadwork zones*. Occupational Safety in Transport Conference, Gold Coast, Australia.

Debnath, A. K., Blackman, R., & Haworth, N. (2015). Common hazards and their mitigating measures in work zones: A qualitative study of worker perceptions. *Safety Science*, *72*, 293–301. https://doi.org/10.1016/j.ssci.2014.09.022

DITRDCSA (2024). *Annual Trauma.* Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts. Retrieved from: https://datahub.roadsafety.gov.au/progress-reporting/annual-trauma

DTMR (2024). Queensland Guide to Temporary Traffic Management Part 5: Short-Term Low-Impact Worksites. Retrieved from: https://www.tmr.qld.gov.au/-/media/busind/techstdpubs/Traffic-management/QGTTM/QGTTM-Part-5.pdf?la=en

Fontaine, M. D., & Carlson, P. J. (2001). Evaluation of Speed Displays and Rumble Strips at Rural-Maintenance Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, *1745*(1), 27–38. https://doi.org/10.3141/1745-04

Fowler, C., Clark, S., Rillie, I., Cuerden, R., & Smith, L. (2011). Development of the Measurement of Injury Risk (MIRi) Index. *Unpublished Project Report CPR1106, TRL: Crowthorne, UK*.

Fudala, N. J., & Fontaine, M. D. (2010). *Work Zone Variable Speed Limit Systems: Effectiveness and System Design Issues*. Virginia Transportation Research Council.

Garber, N. J., & Zhao, M. (2002). *Crash Characteristics at Work Zones*. Virginia Transportation Research Council.

Glaze, S., Ramnath, R., Mitchell, J., & Palmer, M. (2020). *Automating high risk road works processes-quantifying the benefits*.

Idewu, W. I. A., & Wolshon, B. (2010). Joint Merge and Its Impact on Merging Speeds in Lane Reduction Areas of Construction Zone. *Transportation Research Record: Journal of the Transportation Research Board*, *2169*(1), 31–39. https://doi.org/10.3141/2169-04

Ishak, S., Qi, Y., & Rayaprolu, P. (2012). Safety Evaluation of Joint and Conventional Lane Merge Configurations for Freeway Work Zones. *Traffic Injury Prevention*, *13*(2), 199–208. https://doi.org/10.1080/15389588.2011.644606

Joerger, M. (2010). *Photo Radar Speed Enforcement in a State Highway Work Zone*. Oregon Department of Transportation.

Kang, K.-P., Chang, G.-L., & Zou, N. (2004). Optimal Dynamic Speed-Limit Control for Highway Work Zone Operations. *Transportation Research Record: Journal of the Transportation Research Board*, *1877*(1), 77–84. https://doi.org/10.3141/1877-09

Khattak, A. J., Khattak, A. J., & Council, F. M. (2002). Effects of work zone presence on injury and non-injury crashes. *Accident Analysis & Prevention*, *34*(1), 19–29. https://doi.org/10.1016/s0001-4575(00)00099-3

Kwon, E., Brannan, D., Shouman, K., Isackson, C., & Arseneau, B. (2007). Development and Field Evaluation of Variable Advisory Speed Limit System for Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, *2015*(1), 12–18. https://doi.org/10.3141/2015-02

Lee, E.-B., & Kim, C. (2006). Automated Work Zone Information System on Urban Freeway Rehabilitation: California Implementation. *Transportation Research Record: Journal of the Transportation Research Board*, *1948*(1), 77–85. https://doi.org/10.1177/0361198106194800109

Li, Y., & Bai, Y. (2009). Effectiveness of temporary traffic control measures in highway work zones. *Safety Science*, *47*(3), 453–458. https://doi.org/10.1016/j.ssci.2008.06.006

MoT (2024). Safety - Annual Statistics. https://www.transport.govt.nz/statistics-and-insights/safety-annual-statistics/sheet/crash-and-injury-data

National Highways. (2022). *Super swift gates which automatically close off lanes to be trialled on National Highways' network*. GOV.UK. https://www.gov.uk/government/news/super-swift-gates-which-automatically-close-off-lanes-to-be-trialled-on-national-highways-network

NSC (2025). *Car Crash Deaths and Rates*. National Safety Council. https://injuryfacts.nsc.org/motor-vehicle/historical-fatality-trends/deaths-and-rates/

NWSIC (2025). *Work Zone Data*. National Workzone Safety Information Clearinghouse. Retrieved from: https://workzonesafety.org/work-zone-data/

NZTA (2024a). M23 Appendix F: Temporary road safety hardware and devices (Version 4). NZ Transport Agency. https://www.nzta.govt.nz/assets/resources/road-safety-barrier-systems/docs/m23-road-safety-barrier-systems-appendix-f-working-draft-release.pdf

NZTA (2024b). Saving time and money with overnight closures. https://www.nzta.govt.nz/roads-and-rail/new-zealand-guide-to-temporary-traffic-management/rolling-out-the-nzgttm/examples-of-efficient-and-effective-ttm/saving-time-and-money-with-overnight-closures/

Queensland Department of Transport and Main Roads. (2019). *Road Safety Perceptions and Attitudes Tracking Survey 2019: Report on Survey Measures Related to Speed*. Queensland Government Department of Transport and Main Roads.

Rista, E., Barrette, T., Hamzeie, R., Savolainen, P., & Gates, T. J. (2017). Work Zone Safety Performance: Comparison of Alternative Traffic Control Strategies. *Transportation Research Record: Journal of the Transportation Research Board*, *2617*(1), 87–93. https://doi.org/10.3141/2617-11

Sun, C., Edara, P., Hou, Y., & Robertson, A. (2011). *Cost-benefit analysis of sequential warning lights in nighttime work zone tapers*. University of Missouri Department of Civil and Environmental Engineering.

Sun, C., Edara, P., Hou, Y., & Robertson, A. (2012). Safety Evaluation of Sequential Warning Lights in Tapers at Nighttime Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, *2272*(1), 1–8. https://doi.org/10.3141/2272-01

Theiss, L., Ullman, G. L., & Jackels, J. (2024). Improved Temporary Traffic Control Guidance for Mobile Operations on Two-Lane Roadways. *Transportation Research Record: Journal of the Transportation Research Board*, 03611981241235190. https://doi.org/10.1177/03611981241235190

Thomas, J.A., Frith, B., Cooper, D., and Malcolm, L. (2024). *Differences in drivers accessing and progressing through the graduated driver licensing system in New Zealand.* NZTA Research Report 722. https://www.nzta.govt.nz/resources/research/reports/722/

Thomas, J., Tate, F., Frith, B., Malcolm, L., Burton, J., Thomas, F., & Gordon, R. (2023). *Research to support the application of a risk-based approach to temporary traffic management*. NZTA Research Report 708. https://www.nzta.govt.nz/resources/research/reports/708/

Thomas, J.A., and Thomas, F. (2022). Myth-busting for Anxious Older Drivers. Stage 2: Driver Perceptions Survey. AA Research Foundation Report.

TTMISG (2024). Transforming Safety at Roadwork Sites. Temporary Traffic Management Industry Steering Group. https://www.ttm-isg.org/

Ullman, B. R., Ullman, G. L., Dudek, C. L., & Williams, A. A. (2007). Driver Understanding of Sequential Portable Changeable Message Signs in Work Zones. *Transportation Research Record: Journal of the Transportation Research Board*, *2015*(1), 28–35. https://doi.org/10.3141/2015-04

Vignali, V., Bichicchi, A., Simone, A., Lantieri, C., Dondi, G., & Costa, M. (2019). Road sign vision and driver behaviour in work zones. *Transportation Research Part F: Traffic Psychology and Behaviour*, *60*, 474–484. https://doi.org/10.1016/j.trf.2018.11.005

Wolshon, B., Ishak, S., & Idewu, W. (2012). *Design of Lane Merges at Rural Freeway Construction Work Zones*. Louisiana Transportation Research Center.

Wood, R., Palmer, M., Walter, L., & Rillie, I. (2011). *Driver Interaction with Temporary Traffic Management*. Transport Research Laboratory.

Yan, J., Feng, Q., Zhang, C., & Yan, J. (2014). A Comparative Study to Evaluate Short-Term Work Zone Safety Control Measures' Effectiveness Based on a Simplified Traffic Conflict Model. *CICTP 2014*, 2209–2217. https://doi.org/10.1061/9780784413623.212

Yousif, S., Nassrullah, Z., & Norgate, S. H. (2017). Narrow lanes and their effect on drivers' behaviour at motorway roadworks. *Transportation Research Part F: Traffic Psychology and Behaviour*, *47*, 86–100. https://doi.org/10.1016/j.trf.2017.04.016

APPENDIX I: BEST PRACTICE REVIEW

6.1 TTM SETUPS

Effective temporary traffic management (TTM) setups are crucial for improving safety, enhancing traffic flow, and reducing disruptions for drivers and other road users. Studies have shown that lane closures and lane shifts have a direct impact on safety, with lane closures increasing crash rates by between 12–22%, and lane shifts increasing crash rates by nearly 40% (e.g. Rista et al., 2017). One US study by Khattak et al. (2002) found that crash rates during work zone periods are nearly 22% higher than in pre-work periods.

In the New Zealand context, Frith (2016) reviewed crashes at work sites on State Highways over time and found that the overall impact of TTM controls have been positive, and that compared to comparable countries our TTM crash rate is lower (e.g. 38% lower than that of Sweden), indicating value in our approach. His desktop study concluded that TTM would need to reduce crashes at work sites by 40% to pay for itself in safety benefits alone if the cost of TTM was 10% of maintenance costs, and that this type of benefit was conceivable.

Any increase in crash likelihood at work sites can be attributed to many factors, including the uncertainty created by lane realignments, reduced shoulder areas, and speed variances that disrupt normal traffic flow (Rista et al., 2017). Changes to the road layout can also lead to increased driver confusion and hesitancy, as drivers must quickly adapt to altered lanes, narrower passageways, and potentially unclear signage. Confusion can often cause drivers to slow down or reposition abruptly, contributing to irregular traffic flow and heightened collision risk. Stop-and-go traffic patterns (or traffic turbulence) can exacerbate delays, as each sudden deceleration or lane change impacts surrounding vehicles (Yousif et al., 2017).

Managing speed through TTM setups is also a key consideration given that a significant portion of crashes at work sites are linked to excessive speed. According to Brewer et al. (2006), speed was found to be a contributing factor in 42% of crashes at worksites on the Texas state highway system, and Garber & Zhao (2002) found that speed variance at TTM sites played a major role in rear-end crashes, which were found to be the most common type of crash at work zones in Virginia.

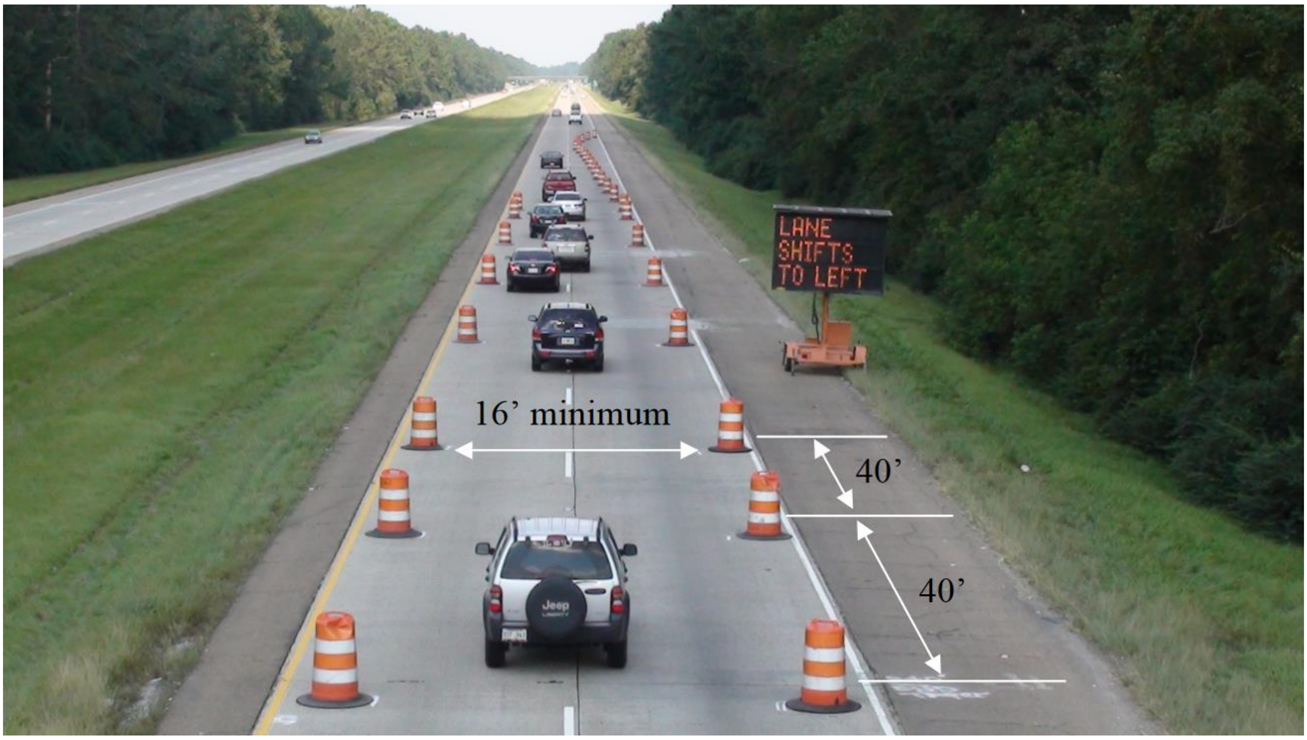
The design of TTM setups plays a significant role in their effectiveness, directly influencing safety outcomes and the level of disruption caused to road users. This includes the design of the lanes themselves. Yousif et al. (2017) studied the impact of narrow lanes in motorway TTM setups on driver behaviour, observing that narrow lanes can cause unsafe repositioning behaviour and greater traffic turbulence, particularly when drivers are near heavy goods vehicles. Based on this, they recommended a minimum lane width of 3.25 metres in locations where there is likely to be many large vehicles passing through.

6.1.1 LANE MERGES AND FLOW

Lane merges are another common point of conflict and delay. New Zealand data shows the capacity of merge lanes (outside of worksites), taken downstream of the SH1 and SH59 merge at Tawa, is about 1400 vehicles per hour (personal communication, Fergus Tate, 06-11-24). This indicates an opportunity to improve flow at worksites by about 200 vehicles per hour (14.3%), improving capacity at the site, and reducing associated delays.

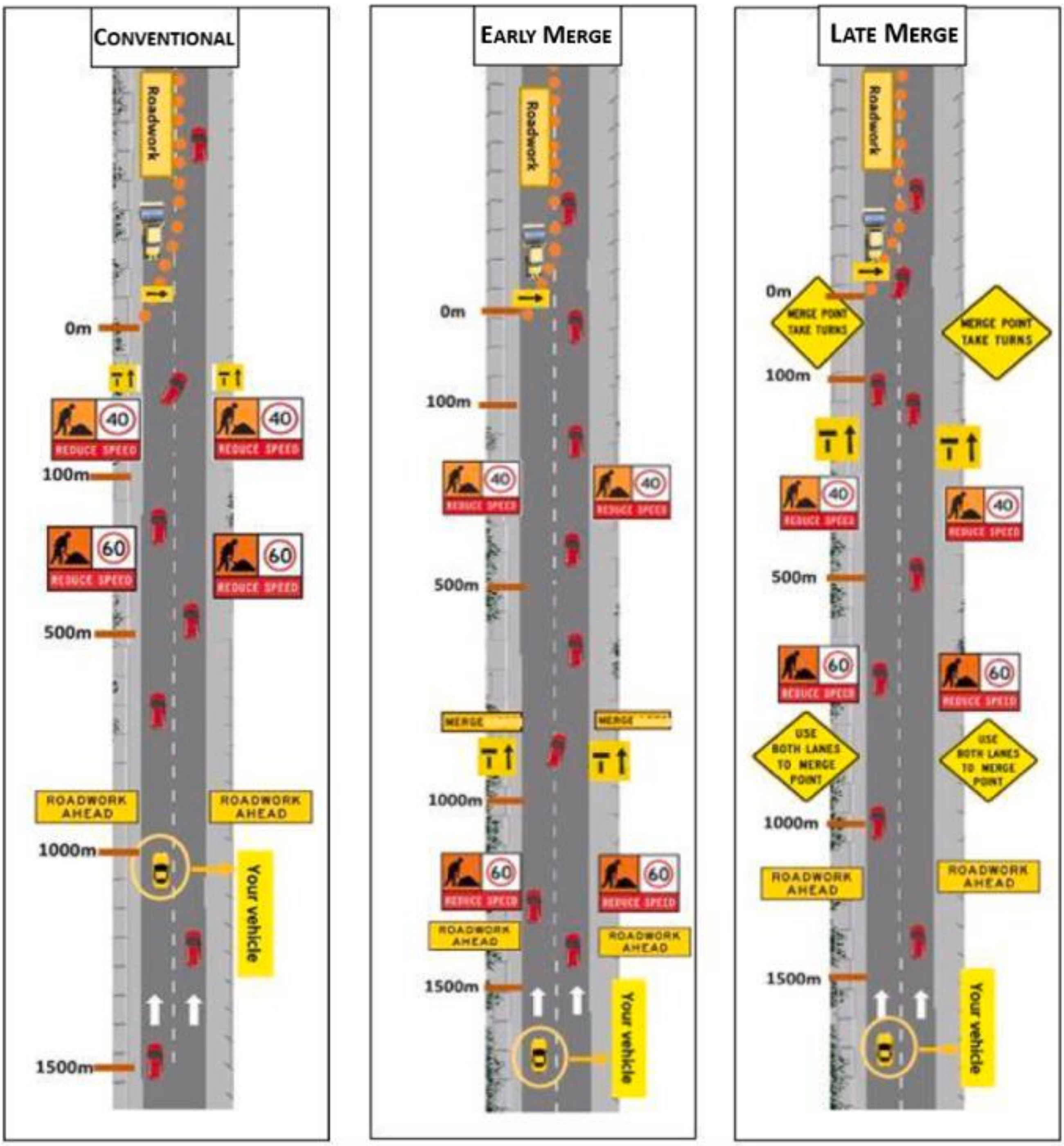
Many TTM setups use a conventional lane merge design, where one lane ends and the other continues through, however there are alternative setups including joint, early and late merges. There have been several studies looking at the impact of using a joint merge design, where both lanes taper off simultaneously (see Figure 12). Also referred to as 'alternating merge' due to the way it encourages drivers in each lane to merge one after the other, the joint merge has been considered as a way to improve the safety and efficiency at the taper, though study findings have revealed mixed results. Ishak et al. (2012) used a microscopic simulation model to test both configurations, finding that the joint merge generally outperformed the conventional merge in terms of safety and efficiency (evident in terms of reduced uncomfortable decelerations and lower speed variance, indicators of smoother traffic and safer flow), but only at low and moderate traffic flow rates. However, observational data reported by Idewu & Wolshon (2010) and Wolshon et al. (2012) found that the joint merge configuration actually performed best at higher flow rates (over 1,200 vehicles per hour) in terms of safety and efficiency, while at lower flow rates the conventional merge was more optimal. Given these mixed findings, the joint merge should be studied further within the New Zealand context to determine whether it is worthwhile including as part of TTM setups.

Figure 12. Example of the joint merge layout (from Wolshon et al., 2012)



In a survey of Australian drivers, Siriwadene et al. (2024) found that Conventional Merge and Early Merge layouts were preferred by drivers (see Figure 13 for examples). Early Merge setups were preferred by females and experienced drivers. Galbraith (2021) indicated that late merge can be inefficient due to poor compliance. Poor compliance is arguably related to the fact that some drivers have anxiety with late merges, especially that other drivers will not let them in at the merge point, but also concern they will be negatively perceived by other drivers who believe they are "jumping the queue" (Galbraith, 2021).

Figure 13. Example Australian setups for a) conventional merging, b) early merging, and c) late merging (Source: Siriwadene, 2024)



Harb et al. (2012) also found that early merge setups outperformed late merge setups in simulations informed from data from field trials in Florida. To inform drivers they used a portable variable message signage which displayed the following messages for the Early and Late Merge setups:

- Early merge setup displayed the messages "DO NOT PASS" followed by "MERGE HERE"
- Late merge setup displayed the messages "STAY IN YOUR LANE" followed by "MERGE AHEAD"

They found that when demand volume exceeded 1500 vehicles per hour Early Merges consistently outperformed Late Merges in relation to travel time and vehicles per hour through the work site (Harb et al., 2012). This was consistent even under different levels of driver merge compliance and with different proportions of heavy vehicles in the traffic composition. At sites with 1500 vehicles per hour or lower they found no differences, but for sites over 1500 vehicles per hour they found an improvement of 21% in vehicles per hour (an improvement of about 340 vehicles per hour). When driver compliance was high (over 80%) they also found significant improvement in travel times through the work site at volumes below 1500 vehicles per hour.

6.1.2 EDGE AND CENTRE LINE DELINEATION

Li & Bai (2009) evaluated the effectiveness of a range of TTM measures in reducing fatalities and preventing severe crashes in highway work zones, using data from 655 severe work zone crashes in Kansas. They found that the most effective measure was the use of centre and edge lines, which can help prevent driver errors such as travelling too fast or following too closely. Regression analysis indicated that the presence of centre and edge lines in TTM setups could reduce the odds of fatalities in severe crashes by 55%. In addition, the use of centre and edge lines could also lower the odds of a severe crash caused by speeding by 29%, and the odds of a severe crash caused by following too closely by 19%. A limiting factor of this work was that other conditions that may have confounded the finding were not included in the analysis, for example, locations without lines were more likely to also be unsealed. They discussed how continuous markings can provide visual cues to drivers to help guidance and lane discipline by outlining travel paths, and reduce the chance of errors by clearly delineating lane and road edges when a lane shift occurs (which, as Rista et al. (2017) reported, is a major source of crashes at TTM sites).

6.1.3 BARRIERS AND PROTECTION

Enhanced barrier protection can provide a greater level of safety control to keep traffic out of work areas if lane markings and other delineation features fail to do so, though the choice of barrier protection must be carefully considered to ensure it does not become a hazard if hit by a vehicle. Consolazio et al. (2003) simulated the use of a low-profile portable concrete barrier in a work site, finding that it was successfully able to redirect even large vehicles without causing rollovers. The barrier did not require anchoring to the road as it was able to use the internal resistance from adjacent segments for effective vehicle redirection.

Other TTM measures have also been found to make a difference on safety outcomes, including the use of flasher devices (bright, flashing lights used to enhance visibility and guide traffic through work zones) which reduced the odds of a fatal crash by 58%, and flagger or officer control, which reduced the odds of a severe crash by 56% (Li & Bai, 2009). Yan et al. (2014) also studied various TTM measures and channelising devices, finding that the most effective combination to reduce traffic conflicts was a vehicle equipped with flashing lights and a flagger directing traffic.

6.1.4 SPEED MANAGEMENT

Methods to slow vehicles down include rumble strips, which were found by Fontaine & Carlson (2001) to have a particularly pronounced effect on truck speeds, reducing them by just over 11 km/h (though they had less of an effect on cars and other small vehicles). Speed displays, which detect and show the speed of vehicles in real-time, were also found to be effective, reducing speeds by about 16 km/h (Fontaine & Carlson, 2001).

Cone configurations can be used to reduce speeds. Allpress and Leland (2010) reduced the spacings of cones upon approach to a TTM site at a curve as a perceptual countermeasure to make drivers feel like they were travelling faster. This type of approach aligns with the concept of self-explaining roads, where speed changes align with driver expectations of an appropriate speed. There was a reduction in speed (of about 13% at the start of the work site relative to the baseline (Allpress & Leland, 2010).

The use of variable speed limit (VSL) systems (which adjust the speed limit based on current road and traffic conditions) have been found to be an effective way to significantly improve the uniformity of traffic speeds (an example of a VSL sign is shown in Figure 14). This helps in reducing congestion and enhancing flow under normal traffic conditions, though their effectiveness decreases as traffic volumes approach heavy congestion (Fudala & Fontaine, 2010; Kang et al., 2004). This was put to the test by Kwon et al. (2007) at a worksite on the Interstate 494 in Minnesota, where the use of a VSL system resulted in a significant reduction in speed differences, with a 25–35% decrease during peak periods. This resulted in a 7% increase in the total traffic throughput during the peak morning hours.

Figure 14. Variable speed limit sign (from Fudala & Fontaine, 2010)

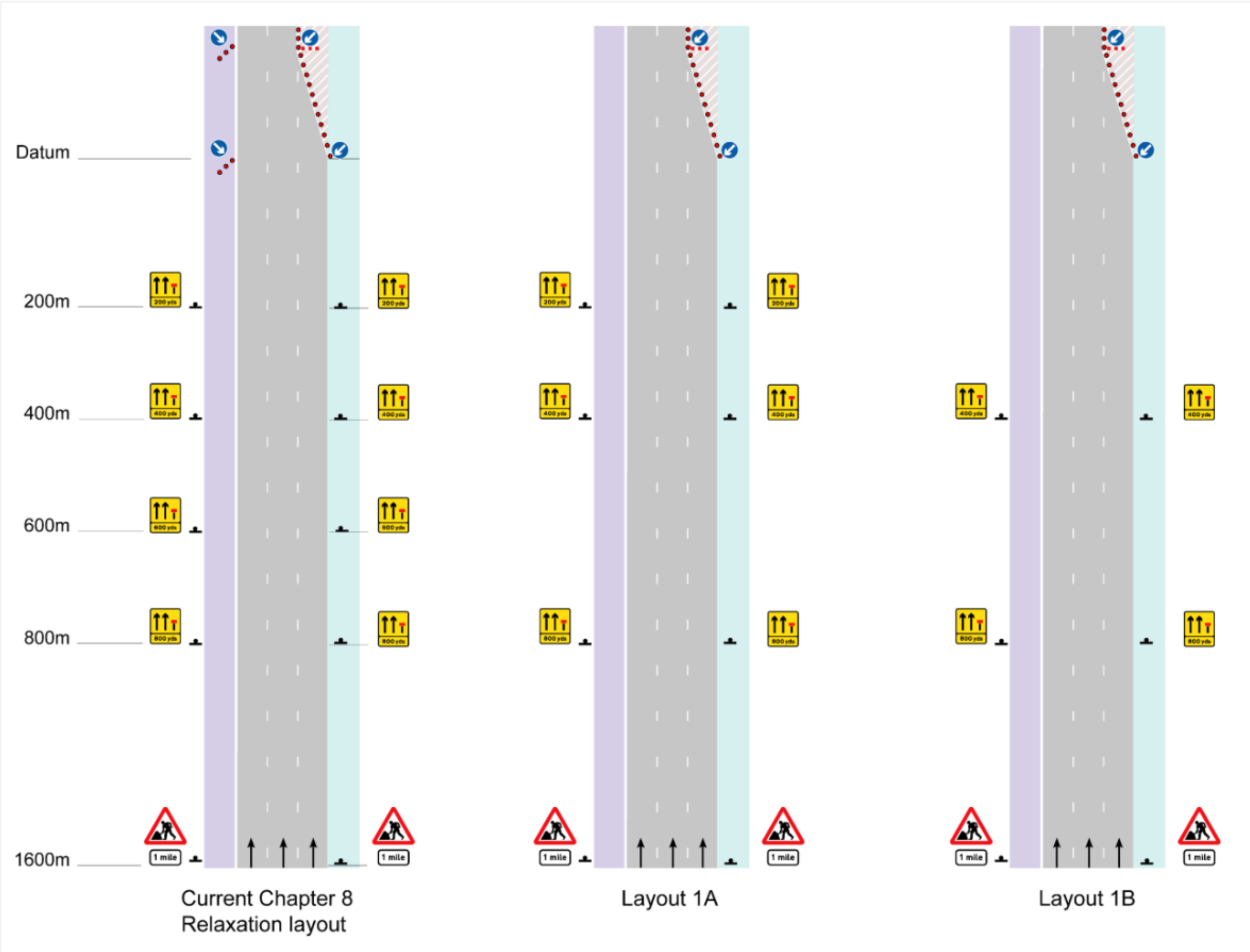
The use of photo radar speed enforcement has been found to be a very effective way to reduce speeds through TTM sites. Benekohal et al. (2010) compared the effects of speed enforcement cameras with other speed management methods like speed displays and police presence at two work zones in Illinois. The results showed that the cameras brought mean speeds to near or below the temporary speed limit. They were as effective as police presence, and were more than twice as effective as speed displays alone. Joerger (2010) reported similar findings at a work site in Portland, finding that the use of speed cameras significantly reduced the number of speeding vehicles in the work zone, and reduced mean speeds by an average of 27%. However, this effect was observed to be temporary, and did not persist beyond the departure of the photo radar van.

Average speed cameras are preferred at longer work sites (over 2km) to promote speed harmonisation and reduce any "yo-yo" speed behaviour in the immediate vicinity of a fixed or temporary speed camera (Thomas et al., 2023, Charlesworth, 2008). Average speed cameras are also in use in TTM sites in the UK, Belgium and Austria, and have been recommended for New Zealand for locations where other speed reduction techniques are not effective (Thomas et al., 2023). In a study of a long-term worksite in Scotland, the speed enforcement technology was altered from fixed to average speed cameras providing a natural experiment (Charlesworth, 2008). Charlesworth (2008) reported improved speed harmonisation and traffic flow, a 91% reduction in speeding tickets, and fewer crashes (from 13 to 0 non-injury crashes).

6.1.5 SIMPLIFIED SETUPS

While adding TTM equipment to a site can often improve safety and efficiency, this is not always the case. There is a balance to strike between a layout that is too complex, which prolongs setup time and potentially puts road workers in greater danger, and one that is too simplistic, failing to provide drivers with adequate information. Wood et al. (2011) studied driver behaviour at three different TTM layouts using a driver simulator and an on-road trial to determine their effectiveness. The first layout was the United Kingdom's currently prescribed TTM layout, referred to as the 'Chapter 8 relaxation layout'. This was modified in Layout 1A to remove the detail on the left-hand side near the taper and the 600-metre warning sign, and in Layout 1B to also remove the 200-metre warning sign. The layouts are shown in Figure 15 below.

Figure 15. Layouts trialled by Wood et al. (2011)



Wood et al. (2011) found that drivers generally behaved safely and consistently across the different setups, and there were no significant changes in safety-critical behaviour when approaching the road works. There was no evidence of a difference in driver response to any of the TTM layouts, indicating that they did not negatively affect driver behaviour. Contractors also supported the simplified layouts.

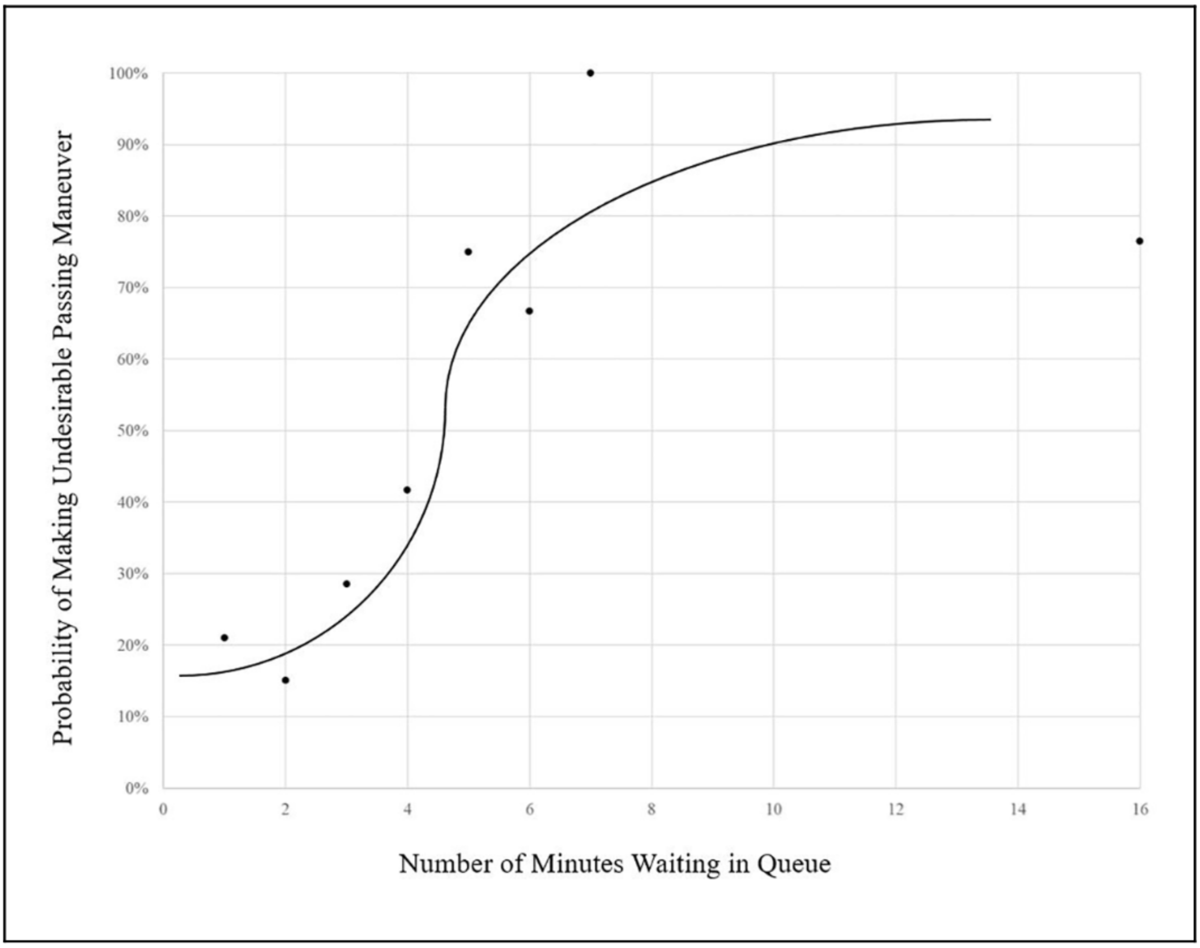
Fowler et al. (2011) expanded on this work by developing the Measurement of Injury Risk (MIRi) index, which aimed to quantify the risks associated with deploying and removing TTM equipment, generally viewed as the highest risk process undertaken by road workers. The highest values on the index are associated with the highest risk levels, while the lowest values are associated with the lowest risk levels. They found that if Layout 1B (shown in Figure 15) is used, the MIRi index could be reduced by up to 22%, and carriageway crossings (a particularly high-risk activity) could be reduced by up to 52%. They also found that if offside signs for nearside lane closures are omitted, this could reduce the MIRi index by 28%, and carriageway crossings by 100%. Combining the two approaches could result in a further reduction of the MIRi index.

6.1.6 MOBILE SETUPS

Mobile work zones involve a particular kind of temporary lane closure where the activities are not confined to a specific location but instead move along the road as the work progresses. Costello & Goluchowski (2006) studied driver reactions to various Visual Enhancement Systems (VES) configurations installed on Truck Mounted Attenuators (TMAs) used at mobile work zones. This was in response to numerous crash events involving TMAs in New Zealand, highlighting the need for effective visual cues to alert drivers. Eight different VES configurations were studied both during the day and night, with their effectiveness based on how far the driver was from the TMA before they changed lanes. The most effective daytime setup had all beacons on, a sequential arrow board, and halogen strobe lights, while the most effective nighttime setup had the same features but without the halogen strobe lights. During the night, the lights from the beacons and arrow board are sufficient to get drivers' attention, but during the day this combination is less effective, requiring the inclusion of halogen strobe lights to enhance visibility. During the day, the best performing VES resulted in a mean lane change distance 60% further back from the TMA than the worst performing, while at night, the best performing VES resulted in a mean lane change distance 35% further back from the TMA than the worst performing (Costello & Goluchowski, 2006).

Theiss et al. (2024) collected data from 17 mobile work zone operations on two-lane roads (one each way) in Texas and Minnesota to study passing manoeuvres. Passing the mobile work convoys involved driving in the opposite lane, so the researchers were interested to see whether drivers did this in a safe manner. They categorised passing manoeuvres by drivers who were not first in queue as 'undesirable', as this indicated impatience. Figure 16 below shows a graph of the probability of a driver making an undesirable passing manoeuvre by the length of time they waited in queue. After about two minutes, the probability sharply increases. Nearly 50% of drivers who waited in the queue for four or more minutes attempted an undesirable pass, which increased to 85% when wait times exceeded six minutes. To minimise the risks associated with these types of passes, the study's authors recommend that mobile work zones only be used when traffic volumes are low and there are plenty of suitable pull over locations. If this is not possible, then a stationary work zone should be used instead.

Figure 16. Probability of an undesirable passing manoeuvre by time in queue (from Theiss et al., 2024)



6.2 DRIVER BEHAVIOUR AND QUALITY INFORMATION

Driver behaviour at TTM sites is crucial for ensuring the safety of both road users and workers, and for optimising the flow of traffic. Poor or distracted driving at work sites increases the risk of accidents while also causing delays for other road users. Providing quality information to drivers can help to improve driving behaviour and compliance at TTM sites, including clear signage, easily navigable layouts, and information about detours. This reduces uncertainty, allowing drivers to make informed decisions and adjust their behaviour (Lee & Kim, 2006).

6.2.1 DRIVER ATTENTION

Debnath et al. (2015) undertook a qualitative study of worker perceptions in Queensland, Australia through interviews with 66 road construction workers, traffic controllers, engineers, and managers. Their findings revealed that drivers often fail to adapt to changed driving conditions at roadwork approaches, leading to incidents such as vehicles driving into the work area, traffic controllers being hit by vehicles, rear-end crashes on the approach, and reversing incidents involving work vehicles and machinery. Workers identified driver errors as the main cause of these incidents. These errors included violating speed limits, distracted driving, and drivers ignoring signage or instructions from traffic controllers when approaching roadworks.

While driver error is a significant factor in TTM incidents, improvements to the design of TTM layouts and the information provided to drivers can help reduce the chances of crashes occurring while also improving traffic flow. Many drivers experience confusion at road work sites, with Queensland's Department of Transport and Main Roads (2019) reporting in their *Road Safety Perceptions & Attitudes Tracking Survey* that 67% of drivers say that it is sometimes difficult to determine the speed limit through a roadwork site. Thomas et al. (2023) also found in their survey of 316 TTM workers that approximately 2 in 5 workers reported road users having trouble understanding and navigating the work site.

Inattention to signage may play a role in this, as discovered by Vignali et al. (2019) in their eye tracking study. Vignali et al. (2019) examined the visual attention of 29 drivers, measuring how often and for how long they looked at signs when travelling through work sites. They found that drivers only fixated on temporary and permanent signage 40% of the time, with a median fixation duration of 1.3 seconds. The most noticeable signs were single signs (rather than sequences of signs along a work site) and signs accompanied by visible roadwork activity. This indicates that at active work sites drivers have a higher visual attention to signage (the corollary being that drivers pay less attention to signs at non-active sites).

Overall, the high rate of inattention to signage may have implications for drivers' comprehension at TTM sites, though the authors note that a possible involvement of peripheral vision in sign detection and identification may also play a role, as the study only considered that a sign had been noticed by a driver if they directly fixated on it for at least 66 milliseconds. When asked about speed at worksites, drivers state more signage would help them (46%), better explanation of the need for the reduction in speed (41%), and speed limits being more distinctive (40%; e.g. flashing speed limit signs; Queensland's Department of Transport and Main Roads, 2019). While Vignali et al's (2019) findings do not necessarily support adding more signage, techniques to make existing signage appropriately distinctive could improve attention to signage. Other improvements that can help are include speed displays (Fontaine & Carlson, 2001), discussed in more detail in Section 0.

6.2.2 DRIVER COMPREHENSION

Signage in general can play a big role in driver comprehension of a work site, with different messages and methods of conveying information having varying impacts on driver behaviour. Bai et al. (2011) studied the effectiveness of various portable changeable message signs (PCMS) in reducing vehicle speeds in a rural highway work zone in Kansas. Three different sign configurations were tested: one with just text, one alternating text and graphics, and one with just graphics (Figure 17). While all three configurations were found to have an impact on driver behaviour, the graphical only sign was the most effective, reducing mean speeds by 17%. This compared to the text only sign which reduced mean speeds by 13%, and the combined sign which reduced mean speeds by 10%. A follow-up survey was also conducted with drivers to ask about the different sign formats, with a majority preferring the graphic format and easily comprehending what the two graphics meant (one showing a worker and the other showing a flagger).

Figure 17. Text PCMS (left) and graphic PCMS (right) (from Yong Bai et al., 2011)

Ullman et al. (2007) also looked at PCMS in Texas, examining whether drivers can combine information from two sequential PCMS into a cohesive message; and if redundancy, by repeating key information across both signs, aids comprehension. Using a driving simulator, the researchers found that when the PCMS contained four or fewer units of information (with one unit being a short message such as 'left lane closed'), comprehension was similar to using a single-phase dynamic message sign (DMS). However, comprehension dropped significantly when five information units were shown. Redundancy did not improve comprehension, as participants were able to recall information from the first PCMS. The researchers also noted that the overall comprehension rates of both PCMS and DMS messages was lower than 85%, indicating the need to keep messages below the four-unit maximum recommended in guidelines. This also assumes adequate sight distance and reading times for all road users.

6.2.3 INFORMED DRIVER CHOICES

PCMS were also used in a study by Lee & Kim (2006) as part of an automated work zone information system (AWIS), designed to provide real-time information to road users on construction activities. The system was tested on a worksite on the Interstate 15 highway in California, where traffic monitoring devices installed along the work zone collected data on traffic conditions, which was then provided to road users via a PCMS which showed messages about expected delay times and/or suggested alternate routes. The information was also made available via a website so that drivers could pre-plan their trips. Using the AWIS led to a reduction in peak hour traffic demand through the work site by up to 18%, with significant volume increases on detour freeways. The system also contributed to a decrease in maximum delay for weekday peak hours, reducing expected delay times by approximately 44% during peak hours.

6.3 SPEED CREDIBILITY AND INACTIVE WORK SITES

Speed credibility is a crucial factor in ensuring compliance with speed limits, especially at inactive work sites. When speed limits remain reduced despite the absence of active work, drivers may perceive these restrictions as unnecessary, leading to potential non-compliance. Over time, this can erode trust in traffic measures, making drivers less likely to adhere to speed limits even when they are necessary for safety (Brewer et al., 2006).

Queensland's Department of Transport and Main Roads' *Road Safety Perceptions & Attitudes Tracking Survey* (2019) provides an interesting insight into how drivers think about speed at roadwork sites. Just over two thirds of drivers report that they are likely to exceed the reduced speed limit at work sites where there are no workers present, while 60% of drivers exceed the limit when they observe other drivers doing the same. For 45% of respondents, the presence of road workers at the site would encourage them to slow down.

Brewer et al. (2006) discussed similar findings, reporting that drivers tend to travel as fast as they feel comfortable without the threat of enforcement. In work zone areas with reduced speed limits but without indication of active work, drivers will generally maintain the speed at which they were travelling prior to entering the work zone.

Thomas et al. (2023) discussed an unpublished Highways England report on the topic, which found that focus groups often reported significant frustration with roadwork sites where no one was apparently working, causing drivers to lose confidence in advance signing. Simulator trials revealed that drivers who had experienced inactive work sites were more likely to engage in more aggressive driving and shorter following distances. However, outside of evaluation of speed, there appears to be limited published evaluations of the differences in driver behaviour between active and inactive work sites.

To ensure safer behaviours at active work sites some areas in the United States (e.g. Florida) began to include setups with signage and lights aimed at differentiating active and inactive worksites. One risk raised was that if workers forgot to adjust the setup around signage or lights when they began work or left site that this would produce a risk to workers or a undermine the credibility of the signage (see Thomas et al., 2023).

As part of a Smart Work Zone trial, Active Work Zone Awareness Devices (AWADs) were trialled at six pilot sites in Florida, and evaluation by the Florida Department of Transport (FDOT, 2021) found that AWADs alone:

- Decreased vehicle speeds entering arterial work zones by 10%.
- Improved early lane changes and slowing down by 44%; and
- Reduced sudden braking or sudden lane changing by 43%.

The AWADs combines several elements, and was likely effective due to the combination of:

- Dynamic information to capture road user attention.
- Individual speed feedback.
- The knowledge that someone was working on the site and the desire for them to be safe or avoid hitting them (intrinsic motivation); and
- Speed enforcement fines, with fines doubled when people are working (extrinsic motivation).

The authors recommended the use of AWADs be standardised and integrated into practice, in particular on arterials with low to moderate traffic volumes, to reduce driver speed, promote early lane changes, and reduce sudden or risky driver behaviours (see Figure 18; FDOT, 2021).

Figure 18. Active Work Zone Awareness Devices (AWADs), showing a trailer-mounted setup (from FDOT, 2021)

In their review of the effectiveness of speed control measures in roadwork zones, Debnath et al. (2012) found that increased fines, including double fines, do not show strong evidence for their effectiveness. One before/after study included in their review trialled double fines at several sites, and only 28% showed a decrease in the average speed — while half showed no significant changes, and 22% showed increased speeds. They concluded that this may be due to problems with active enforcement (i.e. police presence or speed cameras), as another study cited found that the warning of increased fines has little effect in the absence of active enforcement. While the specific driver behaviour impact of the fine warning component of the AWAD device alone is unclear, it does have clear benefits and is one of the only devices that uses intrinsic motivation to keep our road workers safe at active sites.

6.4 TECHNOLOGY ADVANCEMENTS

Work site fatalities were 5 times higher at night compared with day (US study, Arditi et al., 2007).

Technology innovations in TTM offer the potential to improve the safety, efficiency, and effectiveness of road work sites, particularly at night, which can be an especially dangerous time for both workers and road users (Abraham et al., 2007). Arditi et al. (2007) investigated fatal accidents in highway work zones in Illinois over a five-year period to determine the safety differences between nighttime and daytime construction activities. While nighttime works can save project costs and mitigate the impact on the public by reducing congestion and interference, the study found that the number of accidents occurring at nighttime work zones is significantly higher than at daytime work zones. Calibrated data (to account for various factors that could influence the comparison) shows that the number of nighttime work site accidents is on average five times higher than the number of daytime work site accidents.

However, there are ways to reduce the risk. Sun et al. (2012) evaluated the use of sequential warning lights at tapers at nighttime work zones (Figure 19) at three different TTM sites in Missouri, with one lane out of two closed. The warning lights, which were installed along the taper to provide clearer delineation, were found to lead to a reduction in vehicle speeds. Specifically, there was a decrease in average vehicle speeds by 3.56 km/h and a decrease in the 85th percentile speed by 1.6 km/h, both of which were statistically significant findings. Driver speed compliance increased by 6.7%, and vehicles tended to merge further upstream from the taper with the warning lights installed. Using the lights increased the average merging distance by 6 metres for all vehicles, and 15 metres for trucks. Despite these improvements, there was also an increase in speed variability, which could have an impact on traffic flow.

Figure 19. Sequential warning light (Sun et al., 2012)

An earlier piece of research, Sun et al. (2011), quantified the benefits of using these sequential warning lights. Considering only fatal and injury crashes, they estimated the cost-benefit ratio of deploying sequential warning lights was around 5.18 for a nightly deployment strategy, or 10.7 or a strategy that kept the lights installed on channelisers for the entire duration of the TTM setup. The higher cost-benefit ratio for the latter strategy was due to the time savings of not having to set up the lights each night.

Highly visible personal protective equipment (PPE) also plays a significant role in safety. Abraham et al. (2007) prepared a series of PPE garment assemblies in a simulated nighttime work zone, which was then shown to drivers who were asked to compare the visibility of the different PPE assemblies. They found that the visibility of PPE garments could be improved by adding additional retroreflective bands and by ensuring that there is variability in the retroreflectivity values between primary and secondary PPE garments, and a larger variance in the retroreflectivity values across the garment.

A recent technology solution that could help manage lane closures is the SwiftGate (shown in Figure 20), which is designed to automatically close off lanes during road works, reducing the need for workers to manually set out cones or other lane closure equipment. The United Kingdom's National Highways agency tested SwiftGate at the Hindhead Tunnel in Surrey, which requires regular lane closures for essential maintenance work. The deployment time of SwiftGate takes about 5 minutes compared to 25 minutes for a conventional

Figure 20. SwiftGate installation (National Highways, 2022)

lane closure setup, significantly reducing the safety risk to road workers, while providing drivers a strong visual deterrent to prevent vehicle incursions into closed lanes (National Highways, 2022).

Figure 21. Intellicone Smart Taper system (Chevron Traffic Management, 2021)

Taper strikes are another high-risk event where technology can help. For example, Highway Resource Solutions' Intellicone Smart Taper system (Figure 21, which is a set of interconnected sensors integrated into traffic cones and lamps used in road works. Once installed, it continuously monitors the work zone for any taper strikes or incursions and sends out an alert. The system was trialled at a work site on the A45 road in England, where it reduced how long it took to respond to a taper strike to 58 minutes. Without the system, the strike could have remained undetected for up to two hours. Receiving immediate alerts about a strike also means that the risk to worker and public safety is reduced, by minimising the chance that drivers enter the work zone with a compromised taper (Chevron Traffic Management, 2021).

There has also been some provisional research looking at the potential for automation at work sites, particularly for high-risk activities. Glaze et al. (2020) identified specific high-risk activities that could benefit from automation, including the deployment and removal of TTM equipment such as traffic cones or barriers. However, this technology is still in its early stages, and research on the topic is limited. There is therefore an opportunity for New Zealand to contribute to this research by conducting trials of automation technology at TTM sites.