ABSTRACT

Lack of detailed and accurate safety records on incidents in Australian work zones prevents a thorough understanding of the relevant risks and hazards. Consequently it is difficult to select appropriate treatments for improving the safety of roadworkers and motorists alike. This paper outlines development of a conceptual framework for making informed decisions about safety treatments by 1) identifying safety issues and hazards in work zones, 2) understanding the attitudes and perceptions of both roadworkers and motorists, 3) reviewing the effectiveness of work zone safety treatments according to existing research, and 4) incorporating local expert opinion on the feasibility and usefulness of the safety treatments. Using data collected through semi-structured interviews with roadwork personnel and online surveys of Queensland drivers, critical safety issues were identified. The effectiveness of treatments for addressing the issues was understood through rigorous literature review and consultations with local road authorities. Promising work zone safety treatments include enforcement, portable rumble strips, perceptual measures to imply reduced lane width, automated or remotely-operated traffic lights, end of queue measures, and more visible and meaningful signage.

Peer reviewed paper

An earlier version of this paper was presented at the 26th ARRB Conference, held in Sydney on 19–22 October 2014, where it was short-listed for the best ‘Young Professionals’ paper award. It has been further critically reviewed by at least two recognised experts in the relevant field prior to publication in this Journal (Roads & Transport Research).
INTRODUCTION

While road construction and repair is essential for maintaining and improving the mobility and safety of all road users, the process of building safer roads and roadsides needs to be managed to minimize risks to both motorists and roadworkers. Reports from highly motorized countries including the Netherlands, United States and Great Britain show that around 1-2% of road fatalities occur in work zones (NWZSIC, 2012a, 2012b; SWOV, 2010). Numerous studies have found that crash rates increase significantly during roadworks compared with pre-work periods (Khattak et al., 2002; SWOV, 2010; Whitmire II et al., 2011). Work zone crashes are also reported to be more severe than other crashes (Pigman & Agent, 1990). Compared to some other countries, relatively little is known about work zone crashes across Australia, primarily because it is difficult to identify these crashes in official records (Debnath et al., 2013; Debnath et al., 2014c; Haworth et al., 2002). Thus, it is difficult to obtain accurate comparative information on crash rates, crash severity and other variables of interest. Moreover, lack of detailed information in the crash records often restricts safety analysts’ ability to understand the crash causation process (Chin and Debnath, 2008; Debnath and Chin, 2006; Debnath et al., 2014d). Based on New South Wales data (RTA, 2008), it is estimated that nationally each year at least 50 deaths and 750 injuries occur to workers and the public in work zone crashes with a cost of more than $400 million (Debnath et al., 2012).

Significant maintenance and rehabilitation works are being undertaken on the state road network because of multiple floods in Queensland in recent years. This sharp increase in roadwork activities has been accompanied by a number of roadworker fatalities and injuries. It has also become a cause of driver frustration, resulting from frequent stopping in work zones and associated increased travel times, which might influence driver behaviour and compliance with work zone traffic controls (Debnath et al., 2014a). For example, a recent study of driver speeds in a Queensland work zone (Debnath et al., 2014b) showed that almost all (97.8%) vehicles drove above the posted speed limit in the work activity area. This high rate of non-compliance with roadwork signage poses a significant threat to roadworkers as well as to motorists themselves.

The increased risk in work zones warrants urgent research attention to improve the safety of roadworkers and motorists. However, the conventional safety assessment approach taken by researchers in many countries—analysis of historical crash records to understand work zone safety issues—is not possible in Australia, particularly because of the lack of detailed and accurate crash records. Therefore, it is difficult to understand the safety hazards in Australian work zones and to make informed decisions about appropriate treatments for improving work zone safety. Alternative safety assessment approaches, grounded on data collected from real-world work zones, are necessary to facilitate this process. This approach benefits the safety treatment identification process by allowing analysts to incorporate the views of road transport authorities and enforcement agencies about the feasibility and likely effectiveness of safety treatment implementation. It is arguable that examining these issues from alternative perspectives before implementing safety treatments will help to maximise opportunities for safety improvement through appropriate resource allocation.

This paper presents methods and findings of a major roadwork safety research project undertaken by the Centre for Accident Research and Road Safety – Queensland (CARRS-Q). A key objective of the project is to identify real and perceived hazards at roadworks and to mitigate these hazards through appropriate measures. The paper also outlines the basis of a conceptual framework for making informed decisions about implementing safety treatments in work zones. The critical components in this framework include 1) identifying safety issues and hazards in work zones, 2) understanding the attitudes and perceptions of both roadworkers and motorists, 3) reviewing the effectiveness of work zone safety treatments according to existing research, and 4) incorporating local expert opinion on the feasibility and usefulness of the safety treatments. The framework is thus informed by a comprehensive understanding of previous research, as well as the analyses of data which are context-specific. The framework is operationalised in this case using data collected from Queensland work zones, authorities, agencies and road users. The paper first presents methods and findings of this research project, followed by a discussion of promising safety treatments, concluding with an outline of the conceptual framework for safety treatment selection.
METHOD

In order to identify which safety treatments would be effective in improving the safety of roadworkers and motorists in work zones, a multi-stage methodological approach was taken in this research project (see Figure 1). In the first stage, the safety issues in work zones, both from the viewpoints of roadworkers and motorists, were understood using interview and survey techniques. In addition, motorist behaviour in work zones was objectively measured and analysed in response to the findings obtained from the analyses of safety issues perceived by roadworkers and motorists. The second stage involved identification of safety treatments based on the findings obtained from the first stage where the treatments were targeted to resolve the safety issues identified. Review of literature related to work zone safety treatments and their effectiveness, including experimental trials in work zones across the world, supplemented the safety treatment identification process. In the third stage, road transport authorities and enforcement agencies were consulted to obtain expert opinion on 1) feasibility of implementing the identified safety treatments in Queensland, 2) challenges in implementation, and 3) likely effectiveness of the treatments. These expert opinions then helped to identify the safety treatments likely to be useful in improving the safety of Queensland work zones.

Turning to the specific methodologies of each stage, to understand the safety perceptions of roadworkers (i.e., perceived common incidents, hazards and mitigating measures), sixty six road work personnel participated in semi-structured interviews, including 25 traffic controllers, 15 labourers/machinery operators, 21 managers/engineers/supervisors, and 5 directors/planners. As their descriptions suggest, these personnel were occupied in distinctly different roles and spent different proportions of their working time in the field where they could be exposed to work zone hazards. Interviews were conducted individually and face-to-face over an average period of 20 minutes, with the exception of three interviews which were conducted by telephone.

To understand the perceptions and behaviour of Queensland motorists, an on-line survey was conducted from November 2013 to February 2014. The survey was designed to identify factors influencing driver behaviour in work zones, and also key driver concerns. Recruitment methods used to attract participants included online advertisements, state-wide radio interviews, access to the CARRS-Q research panel1, organisational email list distribution, and snowballing techniques. The survey drew 410 participants in total, 54% male and 46% female, with an average age of 46 years (range 20-90, SD 14.9). Residential postcodes indicate that participants were geographically dispersed in urban, regional and rural areas across the state.

To analyse motorist behaviour in work zones, travel speed data from three long-term work zones (i.e., work zones which require a traffic guidance scheme to operate both day and night and may be left unattended) were collected using pneumatic tube counters. Speed data were collected from various locations in work zones (e.g., upstream, start, and end of activity area) over a continuous seven day period so that a representative picture of travel speeds and speed limit compliance was achieved. This multi-location data, where vehicle type, individual vehicle speed and associated traffic flow characteristics (volume, gap from front vehicle etc.) were identifiable, allowed the identification of locations, time periods, and vehicle types with high rates of speeding.

Identification of work zone safety treatments was done in two steps. First, a list of treatments potentially suitable to address the safety issues identified from the previous steps of this research was generated from the review of literature. Second, field evaluations of safety treatment effectiveness were rigorously reviewed to gain understanding of their potential to improve work zone safety in the Queensland context. It should be noted that most of the reviewed literature came from countries other than Australia; therefore, the findings may not be directly transferable to Queensland work zones.

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1 The CARRS-Q Independent Survey Panel in Road Safety (InSPiRS) consists of a group of Queensland households who agreed to help with road safety research by giving their opinions and sharing their knowledge of relevant issues through surveys, focus groups and other common data collection instruments.
Expert opinion on the feasibility, challenges, and likely effectiveness of safety treatments were planned to be obtained through a series of consultations with representatives from Queensland Transport and Main Roads (TMR) and Queensland Police Service (QPS). Representatives of TMR were consulted in four groups (4-8 participants in each group totalling 22 participants). On a list of safety treatments, participants were asked to provide opinions on their feasibility for Queensland work zones, challenges in implementation, and their potential for improving safety. Participants were also asked to consider safety treatments they thought could be useful but were not listed by the researchers. Consultations followed a semi-structured format in order to allow sufficient discussion among the participants. Similar consultations with QPS as with TMR, the range of questions will be different. The QPS consultations will focus more on existing enforcement processes, the challenges faced in active enforcement, and ways to make the enforcement system more useful.

Each of these research steps outlined in this methodology was approved by the QUT Human Research Ethics Committee. Queensland Police Service Research Committee also approved the step involving consultations with QPS.

RESULTS

Work zone safety issues

As outlined in the Method section, the work zone safety issues were identified in three steps: understanding worker perceptions of safety hazards, driver perceptions of safety hazards, and
analysing motorist behaviour in work zones. Results obtained from these steps are presented below.

Worker safety perceptions

In the semi-structured interviews, participants were asked to recall and discuss any safety-critical incidents that they had experienced or witnessed personally, or heard about directly through colleagues. A range of incidents were subsequently recounted in varying amounts of detail. The most frequently recounted type of incident involved a public vehicle intruding into the work area in a roadwork zone. This was mentioned by 38% of the 66 participants. The next most reported incident type was a traffic controller being hit by a vehicle, recalled by one third of participants. Rear end crashes were the third most frequently reported incident type, mentioned by 29% of participants. Reversing incidents (a work vehicle or machinery reversing onto another work vehicle, machinery, object, or worker) were also mentioned relatively frequently, with 23% of participants having witnessed or heard directly about this type of event. A public vehicle was typically involved in the three most commonly mentioned types of incident (work zone intrusion, hit traffic controller, rear end crash). The fourth most frequently noted incident, reversing incidents, usually involved a work vehicle or mobile machinery.

The most common causes of incidents according to participants were vehicles ignoring signage and traffic controllers (n=26), distracted driving (n=14), driver error (n=6) and drink driving (n=5). With regard to drivers ignoring signage, this is a behaviour that results in speeding through work zones and as such is directly related to arguably the most common and problematic hazard in work zones where public traffic must be accommodated. Ignoring traffic controller instructions (e.g., stop/slow) can result in vehicles driving into work-area/closed-lanes, rear end crashes with vehicles stopping/stopped near traffic controller, or head-on crashes with oncoming vehicles when violating a ‘stop’ instruction. Distracted driving, often due to drivers observing work zone activities or using mobile phones and in-vehicle devices, is likely to cause rear end crashes with preceding vehicles. Drink driving was reported to be associated with speeding and consequently not complying with ‘stop’ traffic controls. Whether involving the travelling public, workers only, or a combination of motorists and workers, human error was the main causative factor cited in the majority of these incidents.

With regard to reversing incidents, participants reported that although there are often measures in place to prevent these, including reversing beepers and spotters, they are not always effective. In particular, reversing beepers are sometimes turned off, ignored or fail to be noticed because workers become desensitized to frequent alarms. In regard to spotters, there are accounts of their instructions being misinterpreted and ignored by drivers working on site. Interested readers are referred to Debnath et al. (2013) where common work zone incidents and their causes are described in detail.

In addition to the common incidents and their associated causes, participants were asked to describe the situations at work when they feel unsafe in order to gain a better understanding of the work zone hazards. The commonly reported unsafe situations include excessive vehicle speeds in work zones (n=40), working in wet weather (n=20), driver frustration and aggression towards roadworkers (n=18), working close to live traffic lanes (n=14), working during night, dawn and dusk hours (n=14), and drivers on mobile phones leading to distracted driving (n=11). While these reported unsafe situations include factors related to the working environment (e.g., weather, visibility, and traffic), drivers actions (e.g., speeding, aggression, and distraction) are again reported to create a significant share of the unsafe situations in work zones.

Participants were asked to describe the specific hazards in the situations they reported feeling unsafe. Excessive speed, particularly in the absence of enforcement, poses a significant hazard to roadworkers as speeding is directly related to severity of incidents. The hazards in working in wet weather include reduced visibility and slippery surfaces, which reduce skid resistance and increase stopping distances, so the chances of not noticing signage/traffic controllers and underestimating required stopping distances are higher. These eventually could lead to failing to stop properly under stop/slow directions and being involved in rear end crashes with vehicles stopped ahead. Although working in rainy conditions is not common, sometimes workers need to continue working in order to meet deadlines and/or to reopen the road to traffic as soon as possible. Driver frustration and aggression was reported as hazardous mainly by the traffic controllers. The forms of aggression reported ranged from verbal abuse to throwing objects,
spitting, and threatening roadworkers. The reported hazards in working close to traffic lanes include throwing of loose materials from pavement by passing traffic, inability to see oncoming traffic properly (often in the hilly and winding roads), and not having an adequate escape path. Reduced visibility and higher numbers of fatigued drivers were the common hazards reported for working during night, dawn and dusk hours. Distracted driving due to mobile phone use - also reported as a cause of work zone incidents - was reported as a significant hazard as this often results in motorists disobeying or not noticing traffic lights and signage. A detailed description of the common work zone hazards can be found in Debnath et. al. (2015).

Findings from the commonly reported work zone incidents, their causes, and unsafe situations at work show that driver actions are responsible for creating most of the hazards in work zones. Speeding, noncompliance with traffic signage and traffic controller instructions, and distracted driving were the common hazardous behaviours in work zones. Other sources of hazards include challenging working environments (e.g., working in wet weather, inadequate escape path) and not maintaining safety practices (e.g., tampering with reversing beepers). While construction companies and workplace safety regulators can to a large extent control worker compliance and behaviour and treat hazards related to improper work environment, changing driver behaviour in work zones is more difficult.

**Motorist safety perceptions**

The survey of Queensland drivers essentially revealed that many drivers do not perceive work zones to be particularly hazardous unless they can see active workers and/or machinery. This is evident in participants’ ratings of how likely their speed would be affected by a range of different safety treatments and circumstances (see Table 1) on a scale of 1 - 5 (1 = Highly unlikely, 5 = Highly likely). The items perceived most likely (including Likely and Highly likely) to affect driver speeds were the presence of workers on road, visible police presence, electronic speed feedback display, high visibility uniforms, and the presence of workers behind barriers. Of those items considered highly likely to affect speed choice, the most prominent were visible police presence (67.1%), presence of workers on the road (63.5%), double demerit points for speeding (42.8%) and speed feedback displays (41.4%).

The importance of apparent site activity is also evident in the free text comments, which were provided by half (206) of all survey participants. Of those who commented, 56% of participants recognised that the credibility of reduced work zone speed limits is undermined by the apparent lack of activity that drivers regularly encounter:

> My perception is that if signs are not covered up after works are done for the day/night then drivers become complacent especially if they are being told to reduce speed due to workers on the road when there is no-one there.

> I believe people are happy to go slow when there is visible activity on the site. Drivers get very frustrated however when the speed reduction signs are kept in place when there is clearly no work/activity going on. This can cause complacency.

It was also evident that numerous participants perceive reduced speed limits to be ‘unrealistic’ (too low in the circumstances) in some cases. Other comments offered by multiple participants reflected a perceived need for ongoing driver education, greater enforcement and penalties, and improved clarity of signage and markings to minimise driver confusion. Some participants felt pressured to speed against their will by other drivers tailgating in reduced speed zones.
Table 1 Motorists’ perceived effectiveness of work zone safety treatments (%)

<table>
<thead>
<tr>
<th>Safety treatments and circumstances</th>
<th>Highly unlikely</th>
<th>Unlikely</th>
<th>Neutral</th>
<th>Likely</th>
<th>Highly likely</th>
<th>Likely or Highly likely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed feedback displays</td>
<td>2.0</td>
<td>3.7</td>
<td>11.6</td>
<td>41.4</td>
<td>41.4</td>
<td>82.8</td>
</tr>
<tr>
<td>'Reduce Speed’ signs</td>
<td>3.2</td>
<td>6.9</td>
<td>18.1</td>
<td>54.2</td>
<td>17.6</td>
<td>71.8</td>
</tr>
<tr>
<td>Flashing amber lights</td>
<td>2.5</td>
<td>4.7</td>
<td>16.1</td>
<td>47.8</td>
<td>29.0</td>
<td>76.8</td>
</tr>
<tr>
<td>Visible police presence</td>
<td>2.2</td>
<td>2.5</td>
<td>3.7</td>
<td>24.5</td>
<td>67.1</td>
<td>91.6</td>
</tr>
<tr>
<td>'Roadwork Speed Limits are Enforced’ signs</td>
<td>4.7</td>
<td>12.3</td>
<td>23.2</td>
<td>38.2</td>
<td>21.7</td>
<td>59.9</td>
</tr>
<tr>
<td>High visibility uniforms for workers</td>
<td>1.0</td>
<td>5.9</td>
<td>14.3</td>
<td>46.7</td>
<td>32.1</td>
<td>78.8</td>
</tr>
<tr>
<td>Reduced speed limits</td>
<td>2.2</td>
<td>6.2</td>
<td>15.1</td>
<td>45.4</td>
<td>31.0</td>
<td>76.4</td>
</tr>
<tr>
<td>Traffic cones</td>
<td>2.5</td>
<td>13.4</td>
<td>23.8</td>
<td>50.1</td>
<td>10.2</td>
<td>60.3</td>
</tr>
<tr>
<td>Increased fines for speeding at roadworks</td>
<td>6.2</td>
<td>9.1</td>
<td>21.7</td>
<td>27.2</td>
<td>35.8</td>
<td>63.0</td>
</tr>
<tr>
<td>Double demerit points for speeding</td>
<td>6.0</td>
<td>9.5</td>
<td>18.2</td>
<td>23.6</td>
<td>42.8</td>
<td>66.4</td>
</tr>
<tr>
<td>Presence of workers on road</td>
<td>0.5</td>
<td>0.5</td>
<td>2.5</td>
<td>33.0</td>
<td>63.5</td>
<td>96.5</td>
</tr>
<tr>
<td>Presence of workers behind barriers</td>
<td>1.0</td>
<td>7.9</td>
<td>13.9</td>
<td>45.9</td>
<td>31.3</td>
<td>77.2</td>
</tr>
</tbody>
</table>

Motorist behaviour in work zones

Travel speeds measured at locations upstream, start, and end of work area showed significant levels of non-compliance with posted speed limits. At the upstream locations (after the first speed reduction sign) of the three work zone studied, 77-98% of vehicles travelled above the posted speed limits with 62-96% speeding by at least 5 km/h above the limit and 19-72% speeding by at least 20 km/h over the limit. In general, the extent of speeding was found to be the greatest at the upstream location in comparison with other locations.

About 66-73% vehicles exceeded the posted speed limit at the start of the work area. A comparison of speed limit non-compliance values under posted speed limits of 40 km/h and 60 km/h showed that motorists speed more (66%) under a 40 km/h limit than under a 60 km/h limit (9%). While there were high levels of non-compliance at upstream and within work areas, speeding was less prevalent at the end of the work area. Only 7% vehicles violated speed limits in one work zone, whereas the other work zones saw about 50% and 80% non-compliance rates. Comparison of day and night speeds showed higher night speeds at the upstream location (6-13 km/h higher) and at the end of work area (about 5 km/h higher). However, the results for the start of work area were inconclusive.

A traffic controller performing stop/slow operation was found to have a significant speed reduction effect. Mean speed after the controller was about 10 km/h lower than the posted limit of 60 km/h. However, the mean speed at night was 13 km/h more than that during daytime, suggesting an issue with drivers having difficulty noticing traffic controllers in poor light conditions.

Regression analysis of the speed data showed a greater rate of non-compliance during the afternoon (3-6pm) compared to other daytime hours. In addition, light vehicles were more likely to be non-compliant than medium and heavy vehicles. Similarly, vehicles following a light vehicle were more likely to exceed speed limits than those following medium/heavy vehicles. Likelihood of a vehicle being non-compliant was higher when there were more vehicles around (higher traffic volume) and more vehicles were non-compliant.
Summary of safety issues

Synthesising the findings from the above studies revealed several key safety issues in Queensland work zones. First, the approach area of a work zone (i.e., upstream of work area) is the most safety critical area identified both from the perceptions of roadworkers and drivers’ speed profiles. Common types of incidents, such as work area intrusion, rear end crashes, and traffic controller hit by vehicle generally occur in this area. Moreover, motorists are guided to stop, change lanes and/or reduce speed to minimum levels while travelling through this area. These actions create more conflicts among vehicles and increase the variability of speeds in a traffic stream, thus increasing the likelihood of crashes.

Second, non-compliance with posted speed limits was identified as a key concern. While drivers’ speed profiles showed higher rates of non-compliance upstream of the work area, there were significant levels of non-compliance at other areas within the entire work zones (e.g., at the start and end of work area). The driver survey also revealed that drivers tend to have negative feelings about the reduced speed limits in work zones, particularly when they feel the signage is inappropriate or do not see any workers/works present. Combined with frustrations caused by frequent stopping in work zones and associated delays, such feelings may contribute to high rates of non-compliance, and reduced effectiveness of speed control treatments.

Third, the survey among drivers revealed that some feel pressured when other drivers tailgate in a reduced speed zone. This phenomenon of one driver’s speed being influenced by other drivers was also evident in the observed speed data. In addition, specific groups of drivers, such as those driving a light vehicle or following a light vehicle, were found more likely to violate speed limits than others.

Fourth, improved driver education and awareness of work zone hazards were highlighted by roadworkers as a necessity for improving the safety in work zones. Motorists’ speed profiles also reflect that there is a general tendency to ignore speed limit signage. However, this issue of lack of driver education was not brought up by the experts in the consultations. Changing driver behaviour through education and training usually requires significant time and the effects are often not distinguishable from the effects of other safety treatments (Debnath et al., 2012). This might be a reason why experts focused more on safety treatments which have direct and measurable effects on improving roadwork safety than on driver education.

Review of the effectiveness of safety treatments

The foregoing discussed the safety issues identified through analysis of the safety perceptions of both the roadworkers and motorists, as well as from analysis of drivers’ speeding behaviour in work zones. As outlined in the method section, a list of safety treatments was generated based on these identified safety issues. A thorough review of literature was conducted to understand the potentials of the treatments to improve work zone safety. This section summarises the review outcomes.

Work zone safety treatments can be broadly categorized based on their functional characteristics as Informational, Physical, Enforcement, and Educational treatments. The informational treatments provide motorists with information related to work zones, speed limits, penalties for traffic law violation, real-time cruising speed of individual motorists, and hazard warnings. Physical treatments aim to influence motorists’ speeds by placing traffic calming devices on pavement which generate sound, vibration or optical illusion to affect drivers’ perceptions of speeds. Enforcement and related treatments encourage speed limit compliance by speed monitoring, detection of violations, administration of penalties, and presence of police cars. Educational treatments aim to improve road users’ awareness of the risks at work zones through public campaigns and driver training programs.

Informational treatments

Speed limit signs are generally found to reduce speeds in work zones, but not to the posted limits. Haworth et al. (2002) reported that average travel speeds at sites where speed limit signs were coupled with the standard warning signs were lower than those at sites with warning signs alone. Drivers evidently reduced their average speeds by about 10-15 km/h when they passed a 60 km/h sign while travelling from a road segment with an 80 km/h limit. In a Victorian survey
(VicRoads, 1990), only 43% of drivers reported adjusting their speeds according to speed limits. About 14% and 30% chose their speeds based on their perception of suitable speed and road conditions, respectively, without regard to the posted limits. The remaining 13% reported that they failed to notice the speed limit signs or felt that the signage was inadequate.

Advance warning signs seem to have less effect on speeds than regulatory speed limit signs. A Victorian study (VicRoads, 1990) concluded that advance warning signs do not affect speeds. Similarly, Huebschman et al. (2003) observed no statistically significant speed reductions at work zone approach when warning signs were combined with speed limit signs.

Variable message signs (VMS) produce larger speed reductions than traditional static signage. Brewer et al. (2006) and Bai et al. (2010) showed VMS to be more effective than traditional traffic control devices in reducing the number of speeding vehicles. Fontaine et al. (2000) found VMS in combination with speed feedback systems reduced speeds by up to 16 km/h and lowered the percentage of vehicles speeding, whereas VMS alone resulted in about a 3 km/h speed reduction. Similar findings were also obtained by Maze et al. (2000). Meyer (2000) found speed feedback systems more effective than police presence in reducing speeds in work zones. VMS and speed feedback systems were also perceived as important work zone safety measures by 92% and 87% of respondents, respectively, in a British survey (MVA Consultancy, 2006). Some researchers argued that the effects of VMS and speed feedback systems are temporary. Meyer (2004) found that radar-activated VMS had only a "novelty effect" which was not sustained over time but other research (Wang et al., 2003) found effects three weeks after installation.

Innovative and attention-grabbing messages were tested by Wang et al. (2003), finding immediate speed reductions of 0.3-2.9 km/h in daylight conditions in one worksite, but another site showed little effect. However, speeds continued to decrease over time compared to speeds observed immediately after message deployment. Researchers in Indiana displayed the number of traffic fines issued to date, but found this ineffective (Huebschman et al., 2003).

Physical treatments

Inconsistent findings have been obtained on the effectiveness of rumble strips in reducing speeds. Meyer (2000) found that orange coloured rumble strips significantly reduced the speeds of both cars and trucks. Fontaine and Carlson (2001) observed 2 mph smaller speed reductions for cars in comparison with trucks and reduced percentage of vehicles exceeding the posted limit. However, Horowitz and Notbohm (2005) found that speed reductions due to rumble strips were not constantly present in a Missouri study. Having examined the inconsistent findings and considering the factors related to deployment of rumble strips (e.g., time to lay the strips, workers exposed to traffic), it could be argued that the rumble strips seem ineffective for transient and moving work zones.

Optical speed bars were found to have relatively small but statistically significant reductions in speeds and speed variations (Meyer, 2004). However, because of their relatively small speed reduction ability, they were not recommended for highway work zones where large speed reductions are necessary.

An Australian study (Brindle, 2006) showed that portable speed cushions are effective in reducing work zone speeds. The 85th percentile speeds and mean speeds in an urban arterial work zone (posted speed limit was 40 km/h) were about 40 km/h and 30-35 km/h, respectively.

Enforcement and educational treatments

Enforcement measures seem to be the most effective means to reduce speeds in work zones but these measures often demand allocation of significant resources (Ross & Pietz, 2011). The presence of a speed camera (Benekohal et al., 2010; Huebschman et al., 2003; Joerger, 2010) or a police car with flashing lights on in worksite has significant effects on improving speed limit compliance. However, the effects are limited downstream of the treatment location (Benekohal et al., 2010, Huebschman et al., 2003). Having a police car with flashing lights upstream of the work zone and a police officer near the end of work zone with an automated enforcement facility could be a better arrangement to discourage drivers speeding after crossing the treatment location. Imposing higher fines for violating speed limits has little effect on speed reduction.
Considerations need to be taken on increasing the likelihood of speeding drivers being detected, instead of only increasing the amount of fines (Haworth et al., 2002).

Educational measures target improved public awareness of work zone safety primarily through public awareness campaigns, and driver education and training initiatives. Such measures have the potential to improve public awareness of the risks involved in work zones, but reliable evaluations are lacking regarding their effectiveness in terms of objective measures of speed reductions (Haworth et al., 2002; Ross & Pietz, 2011). However, it is noteworthy that deployment of safety measures in work zones without proper public awareness of the risks in work zones is unlikely to be effective.

Expert opinions on the usefulness of safety treatments

As described in the method section, expert opinions on the feasibility, challenges, and likely effectiveness of safety treatments were sought to obtain through a series of consultations with representatives from TMR (referred as ‘experts’ hereafter).

A common theme appeared in the consultations was that there is too much signage in work zones, which may often hinder drivers’ ability to comprehend the signs and consequently may influence ignoring them. Leaving signage when workers are not on road and deployment of inappropriate signage were two other issues raised which might cause driver frustration and reinforce deliberate non-compliance with signage. Using uniform signage and complying with use of appropriate signage by contractors and traffic control companies are important in this regard. Some experts argued that the focus should be on making the signage more visible and more meaningful, rather than increasing the number of signs.

Physical safety treatments, such as rumble strips and portable humps, have the potential to reduce driver speeds. In particular, rumble strips have been thought to be generally effective in reducing speeds, reportedly with more effects on trucks. In addition, rumble strips might help reducing rear end crashes at the end of queue under stop/slow operation. Increasing the visibility of the strips was also thought to further improve their effectiveness. However, there remains an issue of the strips getting stolen as these are relatively easy to remove from pavements. Milling (roughing up pavement surface) and use of audio-tactile treatments for creating vibration and noise were also nominated as an alternative to the rumble strips.

Experts had mixed feelings about use of anti-gawk screens. While there is a general perception that anti-gawk screens might reduce driver distraction in work zones (no evaluation study exists), some experts believed that use of the screens could actually make distraction worse as drivers would still try to see though the screens. Furthermore, heavy trucks might clip off the screens and create hazards to workers. However, some experts liked the screens and believe that in addition to reducing distraction the screens could act as a barrier to protect workers from projectiles (high speed vehicles throwing loose objects/stones from pavement surface).

Perceptual safety treatments, such as narrowing lanes using pavement markings or traffic cones, were thought to be effective in reducing speeds. There seemed to be enormous interest in trialling this treatment, particularly because of evidence of its effectiveness in literature. Other forms of perceptual treatments, such as 3D painted potholes on pavement, were highlighted. Safety implications of such treatments are yet to be examined though.

Reducing the exposure of traffic controllers to traffic by using automated or human-controlled traffic lights was perceived to be useful. It was proposed that traffic lights have two phases (red and green, or red and flashing yellow, or red and static yellow), instead of having three phases like a conventional traffic light system, so that the two phases represent the ‘stop’ and ‘slow’ phases used in the current traffic control system. While these lights would allow traffic controllers to stay away from the live traffic lanes, it would be necessary to ensure that both ends of a stop/slow operation do not show ‘slow’ at the same time. Therefore, traffic controllers would need to remain at work zones (but not on roads) for overlooking traffic movements and coordinating the phases at both ends. Having the traffic controllers visible to drivers would also solve any potential problems associated with drivers looking around to find the traffic controller and wondering whether the lights are working correctly in the case of a long ‘stop’ period.
Rear end crashes at the end of queue in stop/slow operation are a major concern, as evidenced by the safety issues identified in this study as well as in literature. Use of emergency hazard lights by the vehicle stopped at the end of the queue (drivers are generally instructed to turn on hazard lights by using static signage in the advance warning area) could increase the visibility of the stopped queue to following traffic. This safety treatment was well-received by many experts, but there were mixed opinions about the compliance rates from drivers. Since this treatment is yet to be evaluated on a large scale, compliance levels of drivers are not well understood. Experts also thought that there is not enough education among drivers about this treatment. Some drivers might perceive hazard lights as indicating that the vehicle in front has broken down (as is a purpose of hazard lights) and eventually try to avoid it by shifting to the next traffic lane, which may be allocated to oncoming traffic, thus increasing risk of a head-on crash. The possibility that some drivers would forget to turn off the lights when the queue is cleared might cause confusion among drivers and create another safety hazard. There was also mention of rumble strips to be used at work zone approaches for alerting approaching drivers of the queued traffic ahead.

The usefulness of work zone intrusion alarms was questioned. It was argued that the amount of time workers have to react and to get out of the way of an intruded vehicle upon hearing an alarm is very limited. Therefore, the alarms might be useful to alert workers working further away from traffic lanes, but not for those who work close to the live traffic lanes.

It was acknowledged that enforcement is not viable when the rate of compliance with speed limits is very low as this might have negative implications because of too many speeding fines issued. Findings from the travel speed analyses in the current research program, as well as from other studies in the literature, showed that the level of compliance can be as low as none at all. It was suggested that in some cases a better technique may be to begin with higher posted limits to achieve greater (though still modest) compliance rates, and to then reduce the posted limits gradually in conjunction with active enforcement.

Point to point speed limit enforcement was another interesting safety treatment thought to have potential to improve speed limit compliance in work zones. While this safety treatment is successfully used outside of Queensland, it is yet to be implemented locally in work zones. Experts believed that this treatment could be useful for speed limit enforcement on motorways. It would be interesting to learn the views of enforcement officers on this treatment’s appropriateness and usefulness, as planned in the future consultations with QPS.

Literature showed that speed feedback systems, when coupled with variable message signs, are effective in reducing driver speeds. However, experts believed that the speed feedback systems are not effective enough because of the absence of active enforcement. Some believed that the systems should provide feedback for both positive driving (e.g., smiley face, thank you for not speeding message) and negative driving (e.g., showing speed values, slow down message) for better influencing driver behaviour. Systems which display driver speeds as well as record photos of non-compliant vehicles were believed to be more effective than the systems which only display speeds. The thought behind this belief was that the photos could be used by police for issuing fines. In general, such thinking reflects that enforcement is the best treatment in work zones. There were several mentions of dummy police cars as an alternative form of enforcement (i.e., passive enforcement only), though it was mentioned that drivers become aware of the absence of active enforcement after some days. The feasibility of deploying different forms of enforcement techniques and their associated challenges will be explored in the consultations with QPS.

A key challenge in trialling new and innovative safety treatments reported by many experts was that such trials are often not well-accepted by contractors. Experts acknowledged that even though contractors are encouraged to trial innovative safety treatments, contractors see the associated cost as a disincentive and are generally likely to complete the job assigned according to the minimum requirements specified in contracts and/or technical standards.
DEVELOPING A FRAMEWORK FOR SAFETY TREATMENT SELECTION

As illustrated above in Figure 1, the current research project has involved multiple processes and stages of consultation, data collection and analysis, in addition to an ongoing process of literature review. As suggested in the introductory section, these multiple processes and stages may be condensed into a conceptual framework comprising four main stages which can guide selection of safety treatments appropriate for particular contexts and situations:

1) Identify safety issues and hazards in work zones
2) Understand the attitudes and perceptions of both roadworkers and motorists
3) Review the effectiveness of work zone safety treatments according to existing research
4) Incorporate local expert opinion on the feasibility and usefulness of the safety treatments.

Flexibility within this framework allows for each stage to consist of multiple components, as is the case in the current study. It is also not entirely necessary to operationalise the framework in the order suggested above. For example, an initial review of existing research literature (including treatment evaluations) will very often precede other project tasks. However, it is arguable that the final stage or task should be to incorporate local expert opinion on treatment feasibility and usefulness, after gaining a comprehensive understanding of the literature.

The potential value of this framework is that it encompasses the full range of available perspectives on safety at roadworks by including not only an appraisal of the scientific literature, but also the often conflicting views of local road users, workers and experts regarding treatment requirements and feasibility. Usefulness of the framework relies heavily on the acquisition of data that are context-relevant and are either derived from around the location/s to be treated or can be reliably transferred from elsewhere. For example, information on rural highway treatments may not be relevant for decisions concerning low speed urban work zones. Similarly, findings on some aspects of road user behaviour in other countries may not be transferrable to Australian road users.

CONCLUSIONS

This paper outlined methods and findings of a major roadwork safety research project in Queensland, Australia. Further, a conceptual framework for making informed decisions about work zone safety treatment selection and implementation was presented. The framework draws on findings from various sources, including safety perceptions and attitudes of roadworkers and motorists, driving behaviour of motorists, review of literature on effectiveness of work zone safety treatments, and expert opinions on the feasibility and challenges of local implementation of the safety treatments. In this paper the framework was operationalised using data collected from Queensland work zones and related authorities and agencies. The process and framework, however, may be replicated using data from other jurisdictions or settings in order to ensure situational relevance and selection of the most appropriate safety treatments in specific contexts.

The current study identified several promising safety treatments appropriate for the study area. Active enforcement seems the most effective for improving drivers’ speed limit compliance, according to roadworkers, motorists, experts and the literature. Speed feedback systems with provision to warn non-compliant drivers as well as acknowledging positive driving show strong potential. There was significant thrust for using more visible and meaningful signage rather than increasing the number of signs. Physical (e.g., rumble strips, surface milling) and perceptual safety treatments (e.g., narrowing lane width) could also have potential to improve speed limit compliance. Reducing the exposure of traffic controllers by introducing automated or remotely-operated traffic lights seems another promising measure for improving worker safety. Identified safety treatments for reducing rear-end crashes at work zone approaches include end of queue hazard lights and rumble strips.
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AUTHOR BIOGRAPHIES

Dr Ashim Debnath is a Post-doctoral Research Fellow at CARRS-Q. He is an expert in surrogate safety modelling and statistical analysis of traffic safety data. His research interests include Work zone safety, Traffic Conflict Technique, Statistical modelling of traffic safety, Two wheeler safety, and Smart and sustainable transport systems. He serves as a member of the Committee on Work Zone Traffic Control (AHB55) of the US Transportation Research Board.

Dr Ross Blackman is a Research Associate with CARRS-Q, having completed his doctoral thesis in March 2012, which compared the use and safety of mopeds, scooters and motorcycles, collectively termed Powered Two-Wheelers. He maintains an interest in several diverse but interrelated areas of road safety research, including vulnerable road users, roadwork safety and rural and remote road safety issues.

Professor Narelle Haworth is a Professor at CARRS-Q. Prof Haworth has extensive experience of research related to road safety in Australia. She is a recognised expert on vulnerable road user safety, roadwork safety, and two-wheeler rider licensing and education. She has published numerous numbers of articles in these research areas. She serves as a member of the Motorcycles and Mopeds Committee (ANF30) of the US Transportation Research Board.