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Common hazards and their mitigating measures in work zones: A qualitative study of worker perceptions

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Abstract

Road construction and maintenance activities present challenges for ensuring the safety of workers and the traveling public alike. Hazards in work zones are typically studied using historical crash records but the current study took a qualitative approach by interviewing 66 workers from various work zones in Queensland, Australia. This supplemented and enhanced the limited available data regarding the frequency and nature of work zone crashes in Australia, provided worker insights into contributing factors, and assessed their opinions on the likely effectiveness of current or future approaches to hazard mitigation. Workers may not be aware of objective data regarding effectiveness, but their attitudes and consequent levels of compliance can influence both the likelihood of implementation and the outcomes of safety measures. Despite the potential importance of worker perceptions, they have not been studied comprehensively to date, and thus this study fills a significant gap in the literature. Excessive vehicle speeds, driver distraction and aggression towards roadworkers, working in wet weather, at night and close to traffic stream were among the most common hazards noted by workers. The safety measures perceived to be most effective included police presence, active enforcement, and improving driver awareness and education about work zones. Worker perceptions differed according to their level of exposure to hazards.

Keywords: Work zone safety, Roadworks, Roadworker, Safety perception, Qualitative study.

1. INTRODUCTION

Reports from highly motorized countries such as the United States (US), Great Britain, and the Netherlands show that about 1-2% of road fatalities occur in work zones (NWZSIC, 2012a, b; SWOV, 2010). While this is a relatively low proportion of all road fatalities, crash

rates appear to increase significantly during roadworks compared to pre-work periods (Garber and Zhao, 2002; Khattak et al., 2002; Whitmire II et al., 2011) and work zone crashes are also more severe than other crashes (Pigman and Agent, 1990).

Hazards in work zones have typically been studied through analyses of historical crash data to identify the factors contributing to the frequency of work zone crashes (Chen and Tarko, 2012; Daniel et al., 2000; Harb et al., 2008; Khattak et al., 2002; Khattak and Targa, 2004; Qi et al., 2013; Venugopal and Tarko, 2000) and their injury severity (Khattak et al., 2002; Khattak and Targa, 2004; Li and Bai, 2008b; Qi et al., 2013). However, the crash data-based approach is often hampered by the lack of detail in official datasets (Chen and Tarko, 2014; Cheng et al., 2012) and the likelihood of under-reporting of work zone crashes (Debnath et al., 2013; Schrock et al., 2004).

To understand the hazards in Australian work zones, the conventional crash data analysis approach taken by researchers across the world is not a feasible option. This is because detailed and accurate data on crashes in Australian work zones are not available in official records (Debnath et al., 2013; Haworth et al., 2002). In Queensland, work zone crashes are identifiable in police-reported crash records only if 'roadworks' is reported as a circumstance contributing to the crash and a public vehicle is involved. A similar situation exists in Victoria, where work zone crashes only need to be reported as such if the work zone is determined by police to have contributed to the crash. For example, a crash may not be recorded as a work zone crash where a driver crashed due to speeding or dangerous driving in the work zone. The crash data deficiencies limit the scope for untangling the common hazards in Australian work zones and therefore little is known about their relative contribution to crash causation.

Studies utilizing crash data from other countries provide valuable insights into work zone hazards, but relatively little is known about what roadworkers think regarding work zone hazards. To the authors' knowledge, only one study has focused on roadworker perceptions (Haworth et al., 2002). This study examined safety by analyzing perceptions of roadworkers working in small groups (up to 6 people). However, medium to large scale work zones involve large groups of workers, whose perceptions about safety in work zones are still not rigorously examined. Therefore, there remains a key gap in the current literature—it is not well-understood what roadworkers perceive to be the hazards in work zones and what countermeasures they perceive to be effective in mitigating these hazards.

Worker perceptions provide an alternative source of information about work zone hazards in the absence of reliable and detailed crash data and guidance regarding the likely acceptance of potential countermeasures. Furthermore, even if historical crash data are available, inadequate information in crash databases often restricts safety analysts' ability to understand the causation process of a crash and, consequently, the hazards associated are difficult to identify. Workers perceptions are also expected to provide additional information when reliable crash data is present. In addition to helping to understand the hazards, worker perceptions could also provide valuable insights into which countermeasures could be useful in improving work zone safety, as such perceptions include firsthand knowledge from experience of working in work zones. The effectiveness of work zone safety countermeasures (e.g., different forms of signage, traffic control devices, regulation and enforcement) has been a subject of considerable research through field evaluation studies (e.g., Benekohal et al., 2009; Brewer et al., 2006; Debnath et al., 2014b; Fontaine et al., 2000; Hajbabaie et al., 2009; Maze et al., 2000; Medina et al., 2009). However, the level of

acceptance by workers of some interventions (changes to traffic control methods, technologies or communication protocols, for example) can influence their actual effectiveness (Carder and Ragan, 2003; Mullen, 2004) and is thus important to understand when considering countermeasure deployment.

This study explores workers' perceptions of the hazards in work zones and their potential mitigating measures. Interviews with sixty-six personnel from various work zones in Queensland, Australia, were qualitatively analyzed to identify the major issues and themes. The analysis identifies common work zone hazards and how they affect the safety of workers. In addition, the study examines workers' perceptions of the effectiveness of countermeasures to improve safety. This paper seeks to fill a significant gap in the current literature by providing a thorough understanding of worker perceptions of hazards and mitigating measures. The paper presents the methodology of the qualitative study, followed by the major themes reported on work zone hazards and how these hazards could be mitigated effectively. Major findings and their implications for work zone safety are then discussed.

2. METHOD

2.1 Study design

In this study, people directly involved in roadworks participated in semi-structured interviews designed to explore the common work zone hazards and their potential mitigating measures. As noted by Mullen (2004), who conducted semi-structured interviews to investigate factors influencing workplace safety behavior, "the semi-structured format allowed the questions to be asked in different sequences that resulted in the issues emerging naturally throughout the conversation". The current study adopted this use of generally broad, unobtrusive and non-directive questions to avoid leading participants toward particular responses or stated positions that may be construed as biased (socially desirable responses for example).

Participants were recruited from government and private organizations undertaking road construction, maintenance and traffic control in Queensland. Participant recruitment was facilitated by the industry partners of this study, including the Transport and Main Roads, Leighton Contractors, GHD, and Australian Workers Union. These organizations were first provided with a brief description of the study to distribute among potential participants, after which consenting volunteers were interviewed. Interviewees were assured that their anonymity would be preserved in any subsequent reports, publications or correspondence with stakeholders and their employers. The QUT Human Research Ethics Committee approved the study in May 2012 (Approval Number 1200000195).

During the interviews, participants were asked "In which situations at roadworks do you feel unsafe and what are the particular dangers in those situations?" to initiate discussion about the common hazards in work zones. Depending on the progress of the conversation, additional questions were asked, including "Do you consider the work vehicles and machinery as dangerous to you as passing traffic?", "Are there any particular types of vehicle you consider more dangerous to you than others?", "If so, why do you think these vehicles are dangerous to you?", "What do you feel is a safe speed?", "Do you think that vehicles travel too fast past where you are working?". To initiate discussion about measures to mitigate hazards in work zones, respondents were asked "What safety practices are used at

your worksite and how effective are they?", followed by "What changes would improve the safety of your worksite?" and "Are there any effective measures you are aware of that are not used at your work site?". This range of questions allowed respondents to discuss the effectiveness of familiar safety measures, as well as new, innovative or unfamiliar measures, including those used outside Queensland.

After piloting with two groups of four and five participants, it was decided to conduct individual interviews to remove the possibility of some participants dominating discussion in a group setting. A total of 66 participants (63 face-to-face and 3 by telephone) were interviewed individually by two researchers. The interviews were recorded using digital voice recorders and later transcribed. Interviews ranged in duration from 7 to 38 minutes, with the majority (72%) taking between 10 and 20 minutes.

2.2 Participants

The 66 participants had an average of 9.84 years of roadwork-related experience. Nine participants were categorized as inexperienced in roadwork (less than 2 years), 35 were experienced (2-10 years) and 22 were very experienced (more than 10 years). Approximately two-thirds of participants (n=43) were working at urban sites when the interviews were conducted. Some participants had experience in both urban (low-speed and motorway) and rural (mostly high-speed undivided) settings. In Australia, most rural roads are undivided with one lane in each direction, with some higher standard sections (two lanes each way, divided) nearer to major cities. Most of the participants were male (n=61) and aged between 30 and 54 years (n=48). There were five participants aged below 30 years and 13 participants aged above 54 years.

Respondents included 25 traffic controllers, 15 laborers and machinery operators, 21 managers, engineers, or supervisors, and five directors, planners, or designers. The participants were classified based on their exposure to traffic. The traffic controllers, who are the first to interact with traffic in a work site, were categorized as 'fully exposed to traffic'. The workers, who usually work behind barriers or have some form of physical protection/separation from traffic, were categorized as 'semi-exposed to traffic'. The remaining participants, who mostly work from offices with occasional visits to work zones, were categorized as 'non-exposed to traffic'.

About 50% (n=32) of respondents worked across the whole work zone, while 11 respondents (all traffic controllers) worked only at either end of the work zone. Another 11 respondents (non-exposed to traffic) worked mostly from offices. Twelve respondents (8 non-exposed and 4 semi-exposed) had an approximately 50-50 split of office and on-site work. About 40% of respondents reported that they are on foot when they work on site, another 47% reported to be mostly on foot and sometimes in a vehicle. Only nine participants (including 7 non-exposed) reported staying inside vehicles when working on site. The high proportion of participants who are on foot while working in work zones indicates that there should have a thorough understanding of the common hazards. Most of the participants worked during daytime (n=49), while seven respondents (including 5 traffic controllers) worked only at night. The remaining 10 respondents had both day and night work experience.

2.3 Qualitative analysis

Transcripts of the interviews were analyzed thematically using QSR Nvivo software (version 10). Due to resource constraints and to eliminate inter-coder biases, all transcripts were coded by the same researcher. This researcher conducted about half of the interviews and therefore had sufficient understanding of the common themes arising in the interviews. This helped the researcher to code the qualitative data into preconceived themes, as well as into emergent themes as the coding exercise progressed. The coding process involved two phases. First, each participant's response was coded as a single theme with 'respondent-question' as the smallest unit coded. Second, data relating to the themes for the units were analyzed for coding to sub-themes under each theme of the first phase. The second phase involved an iterative process of coding as responses to one question were often found to provide clues to the sub-themes for other questions. Since the interviews were semi-structured, participants had the opportunity to respond in detail, often in overlap with responses to other questions. Therefore, multiple coding within and between themes was possible from responses to a particular question.

3. RESULTS

3.1 Common hazards in work zones

Table 1 presents the hazards most commonly reported by the respondents overall, as well as separately for fully-, semi- and non-exposed respondents. About 60% of the respondents reported that most of the drivers exceed work zone speed limits in the absence of enforcement. Respondents believed that drivers knowingly violate the posted limits and drive at speeds they, as drivers, perceive to be appropriate for the road environment. Some also believed that frustration due to delays and too many work zones in close proximity might influence drivers' speeding behavior in work zones.

> *It's the exception for somebody that complies with the (speed) limit. I think that most will do whatever speed they perceive to be the right speed … if you really narrow it down, if it is a really narrow constrained site with lots of gravel for them to drive on and stuff like that, they will slow down. But it's not the signs that are slowing them down; it's actually their perception of what the appropriate speed is (very experienced male project manager).*

Working in wet weather was reported as a hazard by about 30% of the respondents. The specific issues noted were slippery surfaces, reduced skid resistance and greater stopping distances compared to dry conditions. Reduced visibility due to rain was also noted as hazardous:

> *...they shouldn't work in rainy weather. ...you can't see the cars and they have trouble seeing you... Of course, once they have started (working in rain), you have to keep going... So rain is probably the scariest one to work in (experienced female traffic controller).*

Some respondents reported working in rain to meet schedule requirements and/or complete works quickly so that roads can be reopened as quickly as possible.

> *I have been in that situation once (very heavy rain)... normally we would get off the road but the (night) job... was coming to an end and the road had to be*

opened. It would have been more dangerous to leave things as they were... would have been chaos... but still, people were working out there (in) low visibility and heavy rain (experienced male supervisor).

Table 1 Commonly reported hazards in work zones

Hazard	Total frequency[a]	Frequencies by Respondent groups[a]		
		Fully-exposed	Semi-exposed	Non-exposed
Excessive vehicle speeds	40	18	9	13
Working in wet weather	20	12	2	6
Driver frustration and aggression towards workers	18	11	1	6
Working close to traffic stream	14	0	3	11
Distracted driving	11	4	4	3
Working during night hours	9	5	2	2
Working close to machinery	7	1	1	5
Highway works (more unsafe than local street works)	7	5	0	2
Setting up signage	6	4	1	1
Working on hilly and curved roads with restricted escape path	6	3	1	2
Working during dawn and dusk hours	5	2	3	0

[a] Frequency values represent the number of respondents reported a particular hazard

Working in rain or on wet roads was reported as hazardous mainly by the fully-exposed and non-exposed groups. It is reasonable to argue that the adverse effects of rain and wet road (i.e., reduced skid resistance and visibility) are generally observed by traffic controllers as they need to look at the oncoming traffic and instruct them to slow down or stop. Out of the 20 respondents who reported rain and wet conditions as hazardous, 19 work mostly on foot, suggesting that those who remain in vehicles do not perceive wet conditions as hazardous.

Driver frustration and aggression towards roadworkers was nominated as a hazard by many respondents (n=18), mostly traffic controllers. The aggressive driver behavior is not limited to verbal abuse but commonly extends to throwing objects, spitting, or threatening traffic controllers. As the first point of contact for traffic travelling through work zones, traffic controllers often ask motorists to slow or stop and therefore are the primary recipients of driver aggression.

A lot of the general traffic just doesn't want to slow down half the time. You know, "do 40" and they give you the forks or yell abuse at you. I have had that many - It's like a daily occurrence (experienced male traffic controller).

Car drivers seem to show more aggression than commercial drivers, with some exceptions.

The people who abuse you, give you trouble, are the light vehicle - you know, people in the cars... It is not really the commercial guys. They are generally pretty safe (very experienced male project director).

Most of the respondents who reported driver aggression as a hazard were from the exposed and non-exposed groups. Results suggest that most driver aggression is directed to traffic controllers who interact with traffic, but not to workers (who normally do not interact with traffic and often work behind physical barriers). The semi-exposed group might become

aware of this hazard from complaints from traffic controllers. Of the 18 respondents who reported driver aggression, only 1 reported remaining in a vehicle while on site, which implies that the roadworkers who work on foot usually experience/observe driver aggression towards them. It was reported that motorists show less aggression to female traffic controllers than to males.

Working close to a traffic stream was considered to be a hazard by many respondents (n=14). The reasons given involved 1) roadworkers being unsure and worried about the behavior of motorists (speeding, violating rode rules etc.), 2) wheels of passing traffic throwing up material such as stones from the pavement which could hit roadworkers, 3) inability to see oncoming traffic clearly, and 4) not having an escape path. Some respondents (n=7) also reported that working close to machinery is a hazard.

Although traffic controllers and workers have greater exposure to traffic than the non-exposed respondents, the latter group perceived working close to traffic as a hazard more often than the other groups did. A possible explanation of this finding is that the exposed and semi-exposed groups are likely accustomed to working near traffic because of their work roles (e.g., traffic control), while the non-exposed group, who often oversee the safety of the other groups, may be more sensitive to this particular hazard.

Distracted driving, particularly mobile phone use, was reported as another common hazard (n=11) and perceived as a major cause of crashes in work zones (see Debnath et al., 2013 for details). Distracted driving was said to result in motorists disobeying or not noticing signage and traffic lights, which was a major concern to roadworkers. Hazardous phone use by drivers was noted more by the exposed than the non-exposed group, and young females were reported to be on the phone more often than others.

> *Mobile phones is probably the worst one, since I have been doing this job, I can't believe how many people are on their phones. It's unbelievable (inexperienced male traffic controller).*

Roadworkers, primarily traffic controllers and workers who work mostly during day and sometimes during night, felt that roadworks during night, dawn and dusk hours are more dangerous than those during the day hours. Peak hour works were also perceived to be more dangerous than those during off-peak hours. The reasons given for perceiving night works more dangerous than day works were 1) higher number of drunk drivers, trucks, and fatigued drivers, and 2) reduced visibility at night (traffic controllers need to stand away from bright work zone lights as these lights diminish the effectiveness of reflective markers and batons for oncoming traffic). Several participants reported that they see more drunk drivers during night time than during day time (and more on Friday and Saturday nights). Respondents felt that motorists have difficulty noticing traffic controllers and signage during dawn and dusk hours, particularly if the sun is in their eyes and they have their visors down.

> *If you are working in the day-time, they can actually see you... night-time work, even (if) you actually have lights, you can't work under the lights because your clothes don't reflect under the lights and your night-light doesn't reflect under the light. They can't see you. So it's more dangerous at night (experienced male traffic controller).*

> *In the morning, the sun is coming up; extremely dangerous, especially if the road faces east or it's on a crest/curve. In the afternoon, the same when the sun is going down, the winter sun on the western side... I know that they can't see the signs and they can't see me because they are putting their visors down, so I have to wave like hell (experience male traffic controller).*

Roadworkers found highway works more unsafe than urban or local street works, primarily because of high speeds on the highways. Large vehicles (trucks, B-doubles etc.) are very common on highways where often the reduced speed limit is 80 km/h (often exceeded by many drivers), compared with 40 km/h on most urban roads. In addition, some traffic controllers reported that setting up signage was less safe on highways than on urban roads. Some traffic controllers also felt unsafe when doing stop/slow operations on highways due to motorists not obeying instructions and showing aggression. There was a reported tendency among drivers to speed up in response to 'Slow' commands or green lights during stop/slow and portable traffic light operations. This could be seen as an attempt by drivers to ensure that they progress through the work zone before traffic controls change to signal them to stop.

> *When you set up the freeway... you have got your bump-truck and your police officers. But, still, when you are dropping that first K sign (80 km/h sign), they are still going 110 kilometers up here. They are still flaming past you, as you are pulling off the side of the road (inexperienced female traffic controller).*

Working on hilly and curved roads was perceived to be unsafe, mainly because of limited visibility to traffic and not having a proper escape path. On curves, roadworkers are unsure about the oncoming traffic and therefore feel unsafe. Often hilly roads and bridges have limited escape paths due to roadside embankments and/or barriers, thus making roadworkers feel unsafe.

> *There's two things where I feel unsafe: where there is limited visibility and there is no escape route. You can't see it (traffic) coming because it's around a curve or something and you have got nowhere to actually get away in a hurry because it's steep or whatever or there's heavy timber... or there's a big guardrail or something blocking your exit (very experienced male project manager).*

3.2 Unsafe vehicles and machinery

While there is a general perception that passing traffic is a threat to roadworkers, respondents were asked what they think about their work vehicles and machinery. Twenty one respondents reported that they consider passing traffic, work vehicles and machinery equally dangerous to them, whereas 33 respondents rated passing traffic as more dangerous to them than work vehicles and machinery. Only four respondents (who work behind barriers) reported work vehicles and machinery to be more dangerous to them than passing traffic. For traffic controllers, the biggest issue reported was finding an appropriate space to stand which will be away from machinery as well as from traffic. The presence of a wide range of machinery in close proximity to workers (especially during asphalting works) and untidiness of the work zone were the main concerns reported by semi-exposed respondents. They also reported that equipment which swings around is more threatening than that equipment which

only moves forward and backward, because the former has larger clearance requirements and because workers are often unsure which way the equipment is going to swing next.

The reasons given for considering passing traffic more dangerous to roadworkers than work vehicles and machinery were 1) roadworkers are more aware of the potential movements of work vehicles and machinery through beepers and communication than the movements of passing traffic, and 2) work vehicles and machinery are much slower than passing traffic so pose less threat.

> *The passing traffic, definitely... we have controls over our own operators/machines but we have no control over the person that's coming past in the car... that's the one thing that we can't control (experienced male project manager).*

Respondents felt that constant alerts and noise from work vehicles and machinery (e.g., reversing beepers, sound of machines) for a lengthy period could make roadworkers fatigued and less attentive. Alerts could blend with background noises and roadworkers may fail to notice the alerts by being habituated to the alerts.

> *The machinery, the guys on the machines, they just become blasé and you become blasé about the noises. ... It (the alert) blends into the sounds that you hear ...once fatigue starts setting in, which can set in really quickly because you are just standing there, it's hard to concentrate after four/five hours of standing there (inexperienced male worker).*

In response to being asked if they consider any particular type of public vehicle more dangerous to them than others, participants reported that large vehicles including trucks, buses, large SUVs and vehicles towing caravans and boats are more hazardous, though not universally so. The non-exposed group perceived cars to be dangerous more than the other groups. Heavy vehicles were perceived as dangerous mainly because of their size (so have less clearance than cars), while for cars it was largely because they tend to speed more and are quieter than heavy vehicles (so difficult to notice).

3.3 Measures to improve work zone safety

Respondents were asked first to describe the effectiveness of current safety measures in the site they were working at the time of the interview. Roadworkers perceived the available safety measures as effective enough (n=24), but emphasized that they are effective only if motorists obey them. Motorists ignoring, not noticing, or becoming frustrated by too much signage is another frequently reported theme (n=21). This implies that while the safety measures may be appropriate for their intended purpose, lack of public compliance could make them ineffective. While many respondents rated the current safety measures effective, some (n=4) thought otherwise.

The most frequently reported effective safety measure was active police enforcement (see Table 2). About half of the respondents, mostly from exposed and non-exposed groups, said that police presence reduce speeding greatly. About 60% of the respondents also reported that most motorists exceed speed limits in the absence of enforcement.

> *...in my experience on the highway ...we had the police there 24/7 with the radar gun. That's the only way to control it (experienced female senior project engineer).*

Table 2 Commonly reported effective countermeasures

Safety measure	Total frequency[a]	Frequencies by Respondent groups[a]		
		Fully-exposed	Semi-exposed	Non-exposed
Active police enforcement	34	11	4	19
Driver education and work-zone oriented licensing	11	8	1	2
Public awareness of roadwork safety	10	6	2	2
Improving communication among and between workers and traffic controllers	8	3	4	1
Physical separation of workers from traffic	6	0	2	4
Spotters to alert workers of incoming hazards	6	1	0	5
Speed feedback system	5	0	0	5
Speed humps ahead of traffic controller	5	3	0	2

[a] Frequency values represent the number of respondents reported a particular safety measure

The presence of a police car, regardless of the presence of a police officer or whether enforcement is actually carried out, was reported to have a notable effect in encouraging speed limit compliance. However, respondents felt that the effect of police car presence diminishes as soon as the police car leaves the work zone. The use of speed feedback systems in the presence of police was also reported by some non-exposed respondents (n=5) to reduce speeds.

> *The police will not book anyone, if we just hire them to come out to control. While the police are here, the public will do exactly what's asked of them. As soon as the police go, they are all back to doing their 80s, 100s, whatever (very experienced male project manager).*

Apart from enforcement and speed feedback systems, some other commonly noted speed reduction measures include installing speed humps near traffic controllers, using pilot cars to guide traffic through work zones and to keep their speeds within safe limits, and starting the 40 km/h zone (which usually starts from the activity area) in advance of the location of traffic controller so that motorists pass traffic controllers under a lower speed limit.

> *The "workmen 40" (sign) should be in front of the controller, not behind them because behind them is ineffective. The traffic speeds up, so therefore if the last sign before the controller is 60 (km/h), the traffic is doing 80 (km/h) (experienced male traffic controller).*

Respondents felt that there is a lack of public education and awareness about the hazards and driving conditions in work zones. Work zone-oriented driver education and licensing program were perceived as a potentially effective measure to improve their safety, mostly by traffic controllers. Many participants proposed refresher courses to keep drivers aware and updated about the signage and traffic rules in work zones. Some argued that learner driver training does not usually include driving through work zones and therefore novice drivers

remain unfamiliar with the driving conditions and hazards in work zones. Improving public awareness through media campaigns, such as television, radio, and newspaper advertisements, was another commonly prescribed measure.

> *I really do think the public need a lot more education where roadworks are concerned. There is not enough educational material for them. They just do not understand. They have got no idea (very experienced male safety coordinator).*

Improving communication among and between workers and traffic controllers was suggested as a potential safety improvement strategy by some respondents, mostly from the exposed and semi-exposed groups. Those not carrying a radio generally have no idea what is happening behind them, which apparently could result in reversing-related crashes. It was argued that mandatory radio use on a single channel by all personnel present in a work zone would improve communication among them and improve hazard awareness. In addition to better communication, some respondents argued that reversing should be reduced as much as possible in order to reduce reversing-related crashes and where reversing is unavoidable, both radio and reversing cameras need to be used.

> *The workers, they should have a radio as well... If they had a radio, you know, they can reach both of us even when we are beyond visual range... I believe that should be mandatory... (experienced male traffic controller).*

Physically separating roadworkers from live traffic was another emergent theme among the potential safety improvement measures, mostly reported by the semi-exposed and non-exposed groups. Some argued that portable barriers should be available in long term work zones and bump trucks should have both rear and side impact attenuators. It was noted that the installation and removal processes usually restrict the use of barriers to long-term work zones only and while the presence of barriers improves the safety of workers working behind them, traffic controllers still remain exposed to live traffic.

As noted earlier, continuous alerts from machinery and work vehicles (e.g., reversing beepers) could blend with background noise and roadworkers may fail to notice the alerts. To prevent crashes in such situations, some respondents argued a ‘spotter’ could be beneficial. However, respondents reported that some roadworkers tend to disobey the alerts and believe that they understand their safety better than others do.

> *...there's quite a bit of human error (from workers). Due to the attitude - they don't want to take instructions from certain people, you know... everybody is proud of themselves. They think that somebody else telling them what to do is undermining their authority... (experienced female project engineer).*

Some respondents argued that the conspicuity of currently available signage needs to be improved. The suggested options to improve signage visibility include using flashing lights or just simply attaching flags to the signage.

Some other reported measures for mitigating hazards in work zones include the use of anti-gawk screens (i.e., roadside safety screens) to reduce driver distraction, use of more conspicuous and comfortable safety vests, portable traffic lights to reduce traffic controller deployment, increased penalties for violating work zone traffic rules, and changing messages

on variable message sign (VMS) periodically so that drivers do not start ignoring repeated messages.

While many respondents believed that their safety could be further improved by using appropriate measures, a large minority felt that there is no room for further improvement. They perceived that if motorists follow rules and obey the signage the currently available safety measures would be effective enough for ensuring their safety. Only 19% of the non-exposed group indicated that nothing more could be done to improve safety, compared with 42% and 60% of the exposed and semi-exposed groups respectively. This suggests that the non-exposed respondents have a better understanding than the exposed and semi-exposed respondents of the potential for further improvement in work zone safety. Younger respondents appeared more positive than those aged more than 54 years about the potential for further improvement.

4. DISCUSSION

4.1 Perceived hazards in the context of other research

The current study found that the perceived hazards at roadwork sites arise from a range of driver, environmental, worker and equipment factors. Driver factors include speeding, distraction, confusion and lack of awareness, frustration and aggression, impairment, fatigue and general non-compliance with traffic controls. Environmental factors include rain and poor weather conditions, poor lighting, obscured vision, limited working space and noise (ineffective alarms, machinery noise). Worker and equipment factors were less prevalent in the overall findings, but included inattention, lack of appropriate communications (e.g., radios, alarms), limited clearance from machinery, and worker ignorance and arrogance.

Arguably the most frequently researched issue among the driver factors is speed limit compliance (see Debnath et al., 2014c for a review of studies), indicating that the perceptions of participants in the current study are accurate and well-founded on speed-related hazards. Work on rural roads and night works were noted as problematic with regard to speed, while light vehicles were reported by some to be less compliant than heavy vehicles. The views expressed in the current study regarding the high degree of non-compliance with speed limits reinforce those of the earlier Victorian survey (Haworth et al., 2002) in which participants reported a mean rating of 6.8 on scale of 1 (never) to 9 (always) when asked if vehicles travel too fast in work zones.

Other driver factors reported include driver distraction and inattention, confusion, frustration, aggressive behavior, fatigue and impairment. Driver frustration and aggression may originate in part from the large number of road construction, repair and maintenance projects in the study area in recent years (due to severe weather events and increasing demand). Interestingly, while members of the public regularly call for government agencies to ‘fix the roads’, many drivers become annoyed at the inconvenience of subsequent traffic delays.

Among the environmental factors, wet weather related hazards were most commonly reported which include poor visibility, slippery surfaces, limited skid resistance and increased stopping distances compared to dry conditions. These hazards were collectively mentioned by more respondents than any other specific hazard, though the issue is not so prominent in the literature. For example, wet conditions were reported to contribute to only two percent of all

fatal and injury crashes (Li and Bai, 2008a) and less than four percent of crash narratives (Shane et al., 2012). Arditi et al. (2007) found larger numbers of fatal crashes on dry days than wet days, however it was noted that the finding may have been influenced by factors not accounted for, such as less driving and/or more cautious driving in wet conditions. Higher number of dry weather crashes could be observed because of greater exposure of traffic travelling under dry weather—generally more vehicle-kilometers are driven under dry weather than under wet weather. A quantitative comparison of the risks of crashes under dry and wet weather is necessary to properly understand the relative risk of crashes under these weather conditions. Such a comparison would require reliable exposure data (e.g., total vehicle kilometers travelled under dry and wet weather) in addition to crash data. In the current study, the high reporting of wet weather hazards by roadworkers may have been influenced by several periods of unusually heavy rain and severe flooding in the study area in recent years (indeed flood damage was the reason for much of the works at the time of the interviews). Relatively high exposure of the roadworkers to these events may have caused some to readily recall the weather-related hazards.

Visibility and conspicuity issues were mentioned in relation to poor weather conditions, but also in regard to working at night, dawn and dusk, and on curved road sections. Although this hazard was noted rarely by those participants who worked at night, daytime work appears to be safer in many (but not all) situations according to the literature (e.g., Arditi et al., 2007; Ullman et al., 2011). Poor light conditions were also found to influence risky driving behavior in work zones (Weng and Meng, 2012). Working on curved road sections was seen to be hazardous due to limited visual contact between workers and approaching traffic, and their perceptions are supported by other researches on crash data analysis. For example, driver casualty risk increased by 33-182 percent (depending on the type of work) on curves compared to straight sections (Weng and Meng, 2011). The lack of an ‘escape route’ was reportedly problematic, particularly when working on embankments, bridges or where movement is otherwise restricted. This hazard is noted to a limited extent in the literature (Shane et al., 2012; Wang et al., 2013).

4.2 Availability and perceived effectiveness of safety measures

Many study participants suggested that currently available safety measures would be adequate if drivers complied with traffic controls and regulations. Clearly this condition is a substantial caveat to the notion of adequacy regarding safety measures, given the widespread documentation of poor compliance with work zone speed limits. Nonetheless it suggests a perception among participants that measures to improve compliance will bring greater safety improvements than the introduction of new safety measures. Improving compliance with work zone speed limits and other traffic controls can thus be seen as the top priority according to many roadworkers, including those who see no room for further improvement to safety beyond the currently available measures. These views on the issue of compliance are well supported by research evidence (Allpress and Leland Jr, 2010; Hajbabaie et al., 2009; Haworth et al., 2002).

Participants in the study believed that police presence and enforcement was the most effective safety measure, reflecting the findings of field evaluations (e.g., Benekohal et al., 2009; Chen and Tarko, 2012; Hajbabaie et al., 2009), as well as other surveys involving people employed on road construction and maintenance projects (Arnold Jr, 2003; Maze et al., 2000). Respondents in the current study also felt that police presence and enforcement

has little or no lasting effect once removed, which is also consistent with findings from other field evaluation studies (Benekohal et al., 2009).

Although the main objective of police presence and enforcement may be to improve speed limit compliance, it has also been noted to influence driver behavior in other ways, such as discouraging driver inattention and aggressive behavior (Ullman et al., 2010). Additionally, as well as being effective in isolation from other safety measures, passive and active enforcement can improve the performance of other simultaneous interventions such as speed feedback and variable message signs (Maze et al., 2000; Medina et al., 2009). Participants in the current study were not asked to consider the effects of safety measures used in combination as opposed to stand-alone measures, so perceptions regarding these complexities were not examined.

Public education and awareness campaigns were highly regarded by participants in the current study, as well as in other studies on safety perceptions (Haworth et al., 2002) and crash data analyses (Li and Bai, 2008a). Some participants in the current study claimed that there is not enough educational material for learner drivers regarding work zones, although this may not actually be the case. The Queensland road rules booklet (TMR, 2011) describes work zone-related signage in the ‘Hazardous localities’ section. An informative brochure was also produced in 2008 to assist drivers’ safe passage through work zones (Queensland Government, 2008) and was generally thought to have been positively received by its target audience (TMR, 2009). While there are some indications that education and awareness campaigns are potentially effective, a lack of formal evaluations makes it difficult to compare perceptions with evidence from research (Debnath et al., 2012). However, given that study participants were highly supportive of such measures, their direct involvement in designing and delivering educational material in potential future campaigns is worth considering.

Limited effects of static signage on improving safety and their credibility were highlighted by the participants of the current study. Participants recognized that the practice of leaving roadwork signs out when no roadworkers are present contributes to greater complacency and frustration among drivers. However, the consequences of leaving signage out while no work is being undertaken must be balanced against the risks involved in retrieving and later repositioning signage (Haworth et al., 2002).

There was little specific reference to variable message signs (VMS) by current study participants, aside from some support for speed feedback displays in conjunction with police presence, which was thought to generate an effect of perceived enforcement. These perceptions concord with the literature reporting that speed feedback systems may be most effective when used in conjunction with other measures such as enforcement (Fontaine et al., 2000; Maze et al., 2000). Participants also noted that traditional signage is often inconspicuous or not clearly visible, and although VMS was not specifically highlighted as a means to address this, better illumination was suggested and could be achieved by VMS use.

The study found that the safety perceptions of roadworkers differ according to their specific roles. The exposed group of participants noted issues such as wet weather, driver distraction (including mobile phone use) and driver frustration and aggression more frequently than the semi- and non-exposed groups. This is arguably not surprising as these exposed workers have the most direct experience of such hazards. However, some of the non-exposed participants appeared keenly aware of some of the hazards that may affect exposed and semi-exposed workers, such as working close to the traffic stream. As the non-exposed participants

generally work in management and supervisory roles, it is encouraging that they conveyed this awareness of hazards that affect others more directly than themselves. The groups also differed in terms of the perceived effectiveness of safety measures. For example, speed limits enforcement was well supported generally, but less so by the semi-exposed group than the exposed and non-exposed groups. The suggestion that there was no room for further improvement to safety was most prevalent among the semi-exposed group, followed by the exposed and non-exposed group. The finding that perceptions vary according to work roles is consistent with the finding of the Victorian study (Haworth et al., 2002), which interviewed personnel from various work areas (e.g., surveying, heavy vehicle inspection).

While this qualitative study has produced useful insights into understanding the common hazards in work zones and the perceived effectiveness of safety measures, two issues need to be noted. First, the sample size was limited to 66 participants who were commonly working on medium to large worksites in Queensland. Thus, the results may be less generalizable to smaller worksites and other geographical areas. Second, it is possible that some participants externalized responsibility for some adverse events, by attributing fault to other factors (public vehicles for example) in cases where the event may have been contributed to by actions of the participant (Shepperd et al., 2008).

5. CONCLUSIONS

This study used a qualitative methodology in the form of semi-structured interviews to examine the perceptions of road construction and maintenance staff regarding work zone hazards. This helps to fill a key gap in the literature regarding roadworker perceptions of work zone hazards and hazard mitigation measures. Findings of the study showed that the perceptions of study participants differed somewhat according to their specific work roles, however some hazards were universally identified. The main perceived hazards related to non-compliance with reduced speed limits, driver distraction and inattention, driver aggression towards roadworkers, lack of worker conspicuity and adverse environmental conditions. Enforcement and education measures and (to a lesser extent) improved signage were perceived as the most effective means to improve safety in work zones. The actual effectiveness of enforcement (including perceived enforcement) is well documented in the literature, as is the potential for improved signage and information provision, thus supporting the views of roadworkers. However, the literature also suggests that the effectiveness of education measures is less clear than perceived by some participants in the current study. Similarities between the findings of the current study and others analyzing crash data support that examining worker perceptions offers a useful alternative in the absence of reliable and accurate crash records, and is also complementary to the conventional crash data analysis approach.

Several important implications of the findings of the current study were identified. Many roadworkers highlighted a lack of public education and awareness regarding work zone hazards. Education campaigns and inclusion of work zone safety issues in driver training and licensing programs were perceived to offer potential to improve work zone safety. However, future research needs to include a formal and reliable evaluation of such campaigns and programs. Driver aggression towards roadworkers was another commonly reported work zone hazard, although it is rarely recognized in organizational and regulatory policies and practices (Debnath et al., 2014a). This hazard could possibly be addressed by incorporating mitigation strategies into policies and practices in two forms: safeguarding workers from

driver aggression through physical separation or enforcement, and introducing measures to reduce the frequency or severity of driver aggression. Active police enforcement was cited as an effective intervention by many, but there remains a need for proper liaison between roadwork authorities and police to enable effective scheduling of enforcement periods. In addition to the above, future research extending the current study should aim to better understand the effects of working environment (e.g., motorway vs local roads, day vs night work, dry vs wet conditions), worker demographic characteristics, and work characteristics (work load and stress analysis) on their perceptions of safety in work zones.

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