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A review of the effectiveness of speed control measures in roadwork zones

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Noncompliance with speed limits is one of the major safety concerns in roadwork zones. Although numerous studies have attempted to evaluate the effectiveness of safety measures on speed limit compliance, many report inconsistent findings. This paper aims to review the effectiveness of four categories of roadwork zone speed control measures: Informational, Physical, Enforcement, and Educational measures. While informational measures (static signage, variable message signage) evidently have small to moderate effects on speed reduction, physical measures (rumble strips, optical speed bars) are found ineffective for transient and moving work zones. Enforcement measures (speed camera, police presence) have the greatest effects, while educational measures also have significant potential to improve public awareness of roadworker safety and to encourage slower speeds in work zones. Inadequate public understanding of roadwork risks and hazards, failure to notice signs, and poor appreciation of safety measures are the major causes of noncompliance with speed limits.

Introduction

While roadworks are essential for maintaining and improving the mobility and safety of all road users, the safety of roadworkers is a serious concern worldwide. In the United States and the Netherlands, about 2% of road fatalities (SWOV, 2010) and 1.5-2% of all workplace fatalities occur at roadworks (Pegula, 2004). Furthermore, crash rates increase during roadworks (Doege & Levy, 1977; Khattak, Khattak, & Council, 2002; SWOV, 2010; Whitmire II, Morgan, Oron-Gilad, & Hancock, 2011) and work zone crashes are more severe than other crashes (Pigman & Agent, 1990). In Australia, it is very difficult to identify roadwork zone incidents in official records (Haworth, Symmons, & Mulvihill, 2002) and a recently published report (Safe Work Australia, 2012), providing a comprehensive analysis of injuries and fatalities due to work related activities, has not identified roadwork zone incidents. However, based on New South Wales data (RTA, 2008), it is estimated that at least 50 deaths and 750 injuries result from road traffic crashes annually in Australian roadwork zones.

Human errors including driver inattention and excessive speed have been identified as the major causes of roadwork zone crashes (Arnold Jr, 2003; Bai & Li, 2011). Driver inattention, including not noticing road signs, could lead to noncompliance with the lower speed limits usually imposed in roadwork zones. A large number of studies (see Garber and Patel, 1995 for a list) have reported that poor speed limit compliance is a major factor contributing to roadwork zone crashes. Research in Victoria found that more than 40% of cars and more than 70% of trucks exceeded signed speed limits at roadworks (Haworth et al., 2002). Over 60% of drivers were found exceeding the 60 km/h speed limit in another Victorian study (VicRoads,

1990), and 10% and 1% of drivers exceeded the limit by 15 km/h and 30 km/h, respectively. Consistent with these statistics, a state-wide survey of truck drivers in the US found that half of the respondents admitted to exceeding work zone speed limits. Interestingly, 90% of the respondents also considered work zones to be more hazardous than regular road sections, though this did not necessarily translate to compliant behaviour (Benekohal & Shim, 1999). This finding supports assertions that drivers are likely to drive at speeds they perceive to be suitable, or with which they are comfortable, regardless of the posted limits (Brewer, Pesti, & Schneider, 2006; Haworth et al., 2002). It is also consistent with the observation that speeding behaviour depends on the actual location of active work area in a work zone, where the lowest speeds are usually observed (Benekohal & Wang, 1993).

This paper provides a comprehensive review of safety measures used to improve compliance with posted speed limits in roadwork zones. In the following sections, the review method and findings on the effectiveness of the measures, classified into four functional categories, are discussed first, followed by discussion on the lessons learnt and concluding remarks.

Relevant articles were identified in various online databases including the Engineering Village, Science Direct, Google Scholar, and Transport Research International Documentation. Primary keywords used in the search include 'work zone speed', 'roadwork speed', 'speed limit compliance', and the names of safety measures with the word 'speed'. The scope was confined to articles which were published in English language since 1990 and those that mentioned travel speed reduction as an outcome of evaluating the safety measures.

Speed control measures

A wide variety of safety measures are used worldwide to improve speed limit compliance which can be broadly categorised based on their functional characteristics as Informational, Physical, Enforcement, and Educational measures. The informational measures provide motorists with information related to roadworks, speed limits, penalties for traffic law violation, real-time cruising speed of individual motorists, and hazard warnings. Physical measures aim to influence motorists' speeds by placing traffic calming devices on the road surface which generate sound, vibration or optical illusion to affect drivers' perceptions of speeds. Enforcement measures are used to enforce speed limits by automated speed monitoring, speeding detection, imposition of violation fines, and presence of police car. Educational measures target improving road users' awareness of the risks at roadworks through public campaigns and driver training programs.

Informational measures

Two forms of signage are commonly used to convey information to drivers – static signs, and variable message signs (VMS). While static signs display pre-defined messages or symbols on retroreflective and/or fluorescent backgrounds, VMS displays electronic customised messages to alert motorists of the present condition of roadworks. Both types of signage are often coupled with conspicuous devices and materials to improve their visibility to drivers. In this section, the effectiveness of the static signage and VMS are reviewed first, followed by a discussion of the effectiveness of the visibility enhancing devices.

Roadwork signage

Signs deployed on roadwork zones are typically of two types – regulatory traffic control signs and advance warning signs. The regulatory signs are usually placed within a work zone to

display information on speed limits, travelling directions etc. The warning signs are placed ahead of the start of work zone in order to inform motorists about the upcoming roadworks.

Regulatory speed limit signs

Speed limit signs are generally found to be effective in reducing work zone speeds. Haworth et al. (2002) reported that average travel speeds at the sites where speed limit signs were coupled with the standard warning sign (symbolic worker sign) were lower than those at sites with the warning sign alone. Bloch (1998) also found speed limit signs effective in reducing speeds by 7-8 km/h. The signs were found particularly effective in lowering speeds of vehicles travelling 16 km/h faster than the posted limit. Benekohal, Resende and Orloski (1992) reported that drivers' speed reduction profiles in a 2.4 km work zone fell into four distinct categories: (1) considerable speed reductions after passing the first sign (63% of drivers), (2) reduced speeds close to the actual work location (11% of drivers), (3) unchanged travel speeds (11% of drivers), and (4) no significant pattern (15% of drivers).

Although speed limit signs are generally effective in reducing speeds, they do not bring speeds down to the posted limits. Haworth et al. (2002) found that drivers 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. A survey in Queensland (TMR, 2009) reported that about 36% of the participants knowingly disobey speed limits at roadwork zones with a higher share (45%) for drivers aged under 30 years. In a Victorian study (VicRoads, 1990), only 43% of drivers were found to adjust their speeds according to speed limits. About 14% and 30% choose 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 limits were inadequate. While it may be obvious, improving motorists' understanding of the need for speed limit compliance and the risks at roadworks is important to ensure better compliance with posted limits.

Advance warning signs

The advance warning signs (e.g., "ROADWORK AHEAD", symbolic worker sign) seem to have less effect on speed reduction in comparison with the speed limit signs. In a Victorian questionnaire examining road user perceptions of roadwork safety (VicRoads, 1990), it was concluded that advance warning signs do not affect speed reduction. Huebschman, Garcia, Bullock and Abraham (2003) observed no statistically significant speed reductions at work zone approach when warning signs were placed in combination with speed limit signs. A possible reason for this result is that motorists may fail to notice the warning signs, as found for 32% of drivers in the Victorian study. Furthermore, even if drivers notice the warning signs, they may wait to see the regulatory signs before deciding to reduce their speeds.

Variable message signs (VMS)

VMS have more influence on speed reduction than traditional static signage. Garber and Patel (1994) and Garber and Srinivasan (1998) showed that VMS were more effective than the traditional traffic control devices in reducing the number of speeding vehicles, a finding which was further supported by Brewer et al. (2006) and Bai, Finger and Li (2010). Fontaine, Carlson and Hawkins (2000) also found VMS effective in reducing vehicle speeds and improving compliance, although only 1-2 mph reductions were observed.

VMS is often combined with a speed measuring device in order to show drivers their instantaneous speeds and to display messages if they are exceeding the posted limit. Fontaine et al. (2000) found this combination reduced speeds by up to 16 km/h and lowered the percentage of vehicles speeding, whereas using VMS alone resulted in about a 3 km/h speed reduction. Similar findings were also obtained by Maze, Kamyab and Schrock (2000). Meyer (2000) found speed feedback systems more effective than police presence in reducing speeds in work zones. In particular, the speed feedback system was effective in maintaining speed reductions after crossing the speed feedback system, whereas motorists tend to increase speed after passing a police officer (Arnold Jr, 2003). VMS and speed feedback systems are also perceived as important measures to improve roadworker safety by 92% and 87% of respondents, respectively, in a survey (MVA Consultancy, 2006). However, younger drivers, who are less likely to be concerned about roadworker safety and are reluctant to change driving behaviours at roadworks, were found to be less supportive of the measures.

While the VMS and speed feedback systems were found effective in some studies, some researchers argued that their effect is temporary or localised. Meyer (2004) claimed that radar-activated VMS had only a “novelty effect” which was not sustained over time but other research (Wang, Dixon, & Jared, 2003) found effects three weeks after installation. Dixon and Wang (2002) reported speed reductions of 6-8 mph immediately adjacent to the speed feedback system; however the effects did not appear to extend to the active work area.

Displaying innovative and attention-grabbing messages was recommended in FHWA (1998) to enhance the effectiveness of VMS. Wang et al. (2003) tested the message “Slow Down My Dad Works Here” written in a child-like font and found immediate speed reductions of 0.2 to 1.8 mph in daylight conditions in one worksite, but another site showed little effect. However, they found that speeds continued to decrease over time compared to the speeds observed immediately after deployment of the message. In an Indiana study (Huebschman et al., 2003), researchers displayed the number of traffic fines issued to date, but found this ineffective. While it seems that the innovative messages have only small or insignificant effects on speed reduction, having a better effect in daylight implies that increasing visibility of the display panels may result in higher speed reductions.

Measures to increase the visibility of signage

As shown earlier, failing to notice signs is a major cause of noncompliance with speed limits. Many researchers have tested conspicuous materials and devices to improve visibility of signage, worksites, and roadworkers. However, most studies focused on examining how much visibility was increased and what effects the increased visibility had on the overall safety of roadworks. From the limited research that evaluated its effectiveness on speed reduction, mixed findings were reported. Hall and Wrage (1997) used beacons to increase the visibility of speed limit signs, but found this approach ineffective. On the other hand, Haworth et al. (2002) found using a slow-stop bat at the approach to roadworks effectively reduced the number of vehicles exceeding the posted limit. Flashing warning lights were also found to be effective in reducing speeds (Huebschman et al., 2003; Arnold Jr, 2003), maybe because drivers thought the flashing lights indicated the presence of police. Further research is needed to better understand the effectiveness of visibility-enhancing measures on speed reduction.

In-vehicle Systems

To regulate speeds at work zones, Whitmire II et al. (2011) tested in-vehicle visual and audio warning systems and found that the warnings affect motorists’ compliance with speed limits.

Although no significant difference was found between the visual and auditory warnings in terms of speed limit compliance, the researchers recommended the auditory warning because it was responded to more quickly (6 seconds in comparison with 22 seconds for the visual warning). Two other studies (Bai & Li, 2011; Li & Bai, 2009) tested the Emergency Flasher Traffic Control Device (EFTCD), which required vehicles entering a work zone to activate their hazard warning flashers in order to alert following vehicles of the upcoming traffic conditions. The EFTCD reduced the mean speeds upstream of a work zone by 5 mph in a 65 mph zone and the system was well accepted by the drivers (60% of drivers considered the EFTCD motivated them to slow down and 82% recommended its implementation in one-lane two-way work zones). Given the recent advancements of intelligent transport systems and their usage as in-vehicle devices, speed compliance in work zones could be enhanced through proper utilisation of the systems.

Physical measures

Rumble strips and optical speed bars are the most common traffic calming devices used in roadwork zones. 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 at a bridge repair site in Kansas. 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. Inconsistent findings of earlier studies were also reported by Carlson and Miles (2003). 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 examined to evaluate their effectiveness on reducing speeds in Kansas (Meyer, 2004). Relatively small but statistically significant reductions in speeds and speed variations were observed with the greatest effects on cars under daylight. The bars were found to have both a 'warning effect' and a 'perceptual effect'. However, because of their relatively small speed reduction ability, use of the bars was not recommended for highway work zones where large speed reductions are necessary.

Enforcement measures

Improved enforcement practices and technologies are highly likely to encourage and result in greater speed limit compliance, whether at roadworks or not. Generally, enforcement measures in roadwork zones include speed cameras, presence of a police car, and higher penalties for violating traffic rules. These measures often demand allocation of substantial resources, some of which are limited, costly and/or strictly regulated (Ross & Pietz, 2011).

Speed cameras

Enforcement of speed limits by utilising speed cameras has been found to be generally effective. Joerger (2010) found speed cameras resulted in a 27% reduction in speeds in a 40 mph zone in Oregon. Research in Illinois (Benekohal, Hajbabaie, Medina, Wang, & Chitturi, 2010; Hajbabaie, Benekohal, Chitturi, Wang, & Medina, 2009) found reductions of 4.2-7.8 mph in average speeds at the treatment locations. Speed reductions were marginally greater at the site where speeding was more prevalent prior to treatment, as well as in the median

(faster) lane compared with the shoulder lane. Huebschman et al. (2003) also reported a 19% reduction in average speeds during active speed camera enforcement.

While speed camera enforcement is found effective in reducing speeds, the effects can be temporary and localised. Joerger (2010) found that speeding returned to pre-enforcement levels immediately after removal of the camera. However, Benekohal et al. (2010) observed some halo effects for heavy vehicles, although very limited (1.8-2.7 mph) and in only one work zone out of the two studied. The average speeds increased after removal of speed camera, but were significantly lower than the baseline average speeds. Benekohal et al. (2010) investigated spatial effects of speed camera and found that the average speeds and percentage of speeding drivers at 1.5 miles downstream of the camera were lower when enforcement was active than when there was no enforcement. However, the amount of speed reduction was greater at the treatment location than the downstream location, implying that drivers increase speeds after passing the camera but less than usual when no enforcement is present.

Police presence

Visible police presence is one of the most effective speed control measures (Arnold Jr, 2003; Benekohal et al., 1992; FHWA, 1998). Police presence implies to road users that there is a high likelihood of enforcement, whether or not enforcement is actually carried out. According to Arnold Jr (2003), police should ideally be present in a marked police car with lights flashing at the beginning of a work zone. As drivers are known to reduce speeds in the immediate vicinity of police and to then increase speeds once past them, it is also suggested that police presence near the end of the work zone may enhance effectiveness of this measure.

Hajbabaie et al. (2009) examined the effects of four different measures, including photo-radar van, speed feedback, police car without lights flashing, and speed feedback with police car without lights flashing. Each measure was effective in isolation in significantly reducing speeds, but the largest reductions in mean speeds and degree of speeding were achieved with police presence in conjunction with speed feedback. Presence of police car resulted in speed reductions of 4.2-7.8 mph, similar to that produced by photo-radar enforcement. Huebschman et al. (2003) also found 10.6 mph speed reduction because of police car presence. Given the effectiveness of police presence, it could be argued that having flashing lights on could further enhance the effectiveness as this would increase police car visibility, resulting in more drivers becoming aware of the police presence. Furthermore, in a survey of Queensland road users, 85% of participants reported that police presence encourages them to reduce speeds (TMR, 2009). Police presence thus appeared about as effective as 'hazards or dangers' and 'potential to injure a roadworker', indicated by 87% and 82% of respondents respectively as factors that would encourage them to slow down.

While speed cameras were found to have halo effects, police car presence did not show such effects (Benekohal et al., 2010). However, in an earlier study (Benekohal et al., 1992), halo effects were found for trucks but not for cars. Trucks were observed to keep travelling at reduced speeds for at least one hour after the police car left the work zone, which was thought to be resulted from CB radio communications between trucks about the enforcement presence. Huebschman et al. (2003) further reported that the presence of a police car had spatial effects. The effects were present for up to 1.2 miles in a work zone (average speeds were found 6.4 mph slower), but not at a distance of 2.4 miles downstream of the police car.

Violation Fines

Increased penalties for speeding in roadwork zones, including doubled fines compared to other locations, have been implemented in many US jurisdictions. However, many studies do not show strong evidence for the effectiveness of this approach (Ross & Pietz, 2011). A study at work sites prior to and after implementation of higher penalties found that half of the sites showed no significant changes in speed, 28% of the sites observed decreased speeds, and 22% of the sites surprisingly observed increased speeds (Ullman, Carlson, & Trout, 2000). The ineffectiveness of the higher penalties could be due to problems with enforcement, as the law requires workers to be present at site when a higher penalty can be issued. There is also an apparent reluctance of courts to apply penalties in full (Arnold Jr, 2003). Proper enforcement was also problematic because of the physical nature of roadworks. Often roadworks involve narrow carriageways or using the shoulder for traffic movement or works, which make it difficult for police officers to stop a speeding driver. Haworth et al. (2002) conclude that increased fines have little effect in the absence of active enforcement, and that problems with enforcement could potentially be overcome using automated enforcement techniques.

Educational measures

Educational measures target improving public awareness of roadwork safety primarily through two channels: public awareness campaigns, and driver education and training initiatives. Such measures have strong potential to substantially improve safety of roadworkers, but there remains a need for formal and reliable program evaluations (Arnold Jr, 2003; Haworth et al., 2002; MVA Consultancy, 2006; Ross & Pietz, 2011). Unlike the other categories of measures, whose effectiveness has been evaluated objectively in terms of the extent of speed reduced, evaluation of educational measures have typically relied on public perceptions of their effectiveness obtained from surveys. Another problem in evaluating educational initiatives is that it is difficult to separate the effects from those of the speed control measures available in work zones.

In Queensland, a five-year advertising and awareness campaign commenced in 2005 which aimed to raise awareness of roadworker safety issues and to influence driver behaviour (TMR, 2009). As with a safety campaign in Oregon (Ross & Pietz, 2011), the Queensland program sought to personalise the road safety messages and to emphasise the 'human' side of work zone crashes. Survey results revealed that almost all participants (97%) agreed that the campaign encourages drivers to slow down and 93% agreed that the campaign helped them to realise the potential consequences of speeding at roadworks and of disregarding traffic control signals and directions. About 91% of participants reported that the advertisements had made them think about slowing down, while 84% reported actually slowing down. The survey also found that 41% of participants felt negatively towards roadworks, and 36% knowingly disregard speed limits (this was as high as 45% for those under 30 years of age), clearly highlighting the potential for educational interventions.

Pratt, Fosbroke and Marsh (2001) recommended educating people about work zone safety issues and human factors related to safe driving in work zones through public announcements, and driver education and training. Educating road users about the presence and purpose of roadworks, the purpose and legality of speed limits, and appropriate driver behaviour, was also the most frequently suggested measure in a Victorian survey (Haworth et al., 2002). Although formal evaluations are lacking, education and awareness campaigns are likely to be most effective in conjunction with enforcement initiatives (Arnold Jr, 2003; Haworth et al., 2002; MVA Consultancy, 2006; Ross & Pietz, 2011).

Discussion

Despite the inconsistent results obtained in many studies, it is possible to draw conclusions on some aspects of the effectiveness of safety measures. Static advance warning signs have less effect on reducing speeds than the static regulatory signs. Deploying VMS, particularly in combination with speed feedback system, has more influence than the static signage although the effects are often temporary and localized near the vicinity of the sign. Displaying attention-grabbing messages on VMS seems to have no additional effects than displaying standard messages. Inadequate public understanding of roadwork risks and failing to notice signs are the major causes of finding the measures ineffective or less effective. Using conspicuous materials and devices are believed to enhance effectiveness of the signage by making the signage more visible; however, published evaluations are inadequate to draw conclusions regarding their effectiveness. While the informational measures produced mixed findings, the physical measures appear to have relatively small speed reduction ability and are ineffective for transient and moving work zones.

Enforcement measures seem to be the most effective. The presence of speed cameras and police cars with flashing lights in workzones has significant effects on improving speed limit compliance. However, the effects are limited downstream of the treatment location. 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 by itself appears to have little effect on speed reduction. To improve the effectiveness of increased fines, measures to increase the likelihood of speeding drivers being detected need to be put in place.

Educational measures have potential to improve public awareness of the risks involved at roadworks but their effectiveness is difficult to evaluate in terms of objective measures of speed reductions. Public campaigns and driver training programs can change driver perceptions of the need for safety of roadworkers and slowing down in work zones. It is noteworthy to mention that deployment of safety measures in work zones without proper public awareness of the risks at roadworks is unlikely to be effective.

There are several possible reasons for the inconsistent findings regarding the effectiveness of some safety measures. Firstly, often effectiveness of the measures was evaluated in isolation (i.e., only a particular measure was evaluated at a time), thus the combined effects of multiple measures were ignored. It is common to have multiple safety measures present at a work zone and all of them contribute together to reducing speeds. Secondly, effectiveness of the measures could be variable depending on the work zone's geometry (e.g., straight vs. curved road section) and nature (e.g., rural vs. urban roadway, temporary vs. long term work zone). This could explain why a particular safety measure was found effective in some work sites, whereas it was found ineffective in other sites. Finally, the effectiveness of the measures could depend on motorists' driving behaviour and flexibility in adaptation of their behaviours at roadworks. Motorists' behaviour and their adaptation characteristics could be highly variable among motorists of different age groups, localities, and cultures. Therefore, generalization of the findings without considering the characteristics of drivers and work zones may produce misleading results on the effectiveness of safety measures.

Conclusion

This paper discussed the effectiveness of safety measures used in road work zones in order to keep motorists' speeds within posted speed limits. The review of published literature showed that excessive speeds and violation of speed limits were common in many countries. While some of the measures that have been implemented to improve speed limit compliance were found to be effective to a certain degree in speed reduction, the results in many studies were somewhat inconsistent. To better understand the effectiveness of the measures, it is necessary to consider several important factors, such as evaluating safety measures in a combined manner, considering the nature and geometric characteristics of work zones in comparing results obtained from different work zones, and understanding the behavioural differences among motorists of different groups. Despite the inconsistent results, it was evident from the review that the enforcement measures have greater influence on speed reduction than the informational and physical measures. Better speed limit compliance could be achieved if enforcement measures coupled with informational measures are deployed together, given that proper public perceptions on roadwork safety are ensured.

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