



Work zone sign design for increased driver compliance and worker safety



Md Mahmudur Rahman^{a,*}, Lesley Strawderman^a, Teena Garrison^b, Deborah Eakin^c,
Carrick C. Williams^d

^a Department of Industrial and Systems Engineering, Mississippi State University, P.O. Box 9542, Mississippi State, MS 39762, USA

^b Center for Advanced Vehicular Systems, Mississippi State University, P.O. Box 5405, Mississippi State, MS 39762, USA

^c Department of Psychology, Mississippi State University, P.O. Box 6161, Mississippi State, MS 39762, USA

^d Department of Psychology, California State University San Marcos, USA

ARTICLE INFO

Keywords:

Dynamic message sign
Sign content
Refresh rate
Sign placement
Highway construction

ABSTRACT

Many studies have investigated the effect of dynamic message signs (DMS) on drivers' speed reduction and compliance in work zones, yet only a few studies have examined the design of sign content of DMS. The purpose of this study was to develop design standards for DMS to improve driver compliance and worker safety. This study investigated the impact of sign content, frame refresh rate, and sign placement on driver speed reduction, compliance, and eye movements. A total of 44 participants were recruited for this study. Each participant completed 12 simulated driving tasks in a high-fidelity driving simulator. A small-scale field study was also conducted to test the effect of DMS on vehicle speed in a highway work zone. Results showed sign content and placement had no impact on speed reduction and compliance. However, sign frame refresh rate was found to have a significant effect on drivers' initial speed and speed reduction. Participants had longer fixation duration on DMS when worker presence was mentioned in the sign content. Results of the field study suggested that the DMS is most effective at night.

1. Introduction

Struck-by injuries and fatalities are prevalent in the construction industry. According to the National Census of Fatal Occupational Injuries (U.S. Department of Labor, 2016), a total of 318 occupational fatalities occurred in 2014 as a result of workers being struck by vehicles while on the job. Struck-by incidents accounted for 16% of all transportation-related occupational fatalities in 2014. The high prevalence of this class of fatalities emphasizes the need for research to identify practices that would reduce struck-by injuries and fatalities in future years.

A significant proportion of the struck-by injuries and fatalities occur at road construction sites. In 2014 alone, there were 116 fatal occupational injuries at road construction sites. These numbers have remained relatively stable since 2003, ranging from 101 (2008) to 165 (2005) (National Work Zone Safety Information Clearinghouse, 2015). These fatal events accounted for 1.9% to 2.9% (from 2003 to 2010) of all construction related fatal occupational injuries (Pegula, 2013). Among the fatalities in 2014, 46% were classified as a worker being struck by a moving vehicle (National Work Zone Safety Information Clearinghouse, 2015). The cause of these struck-by fatalities in road construction sites could be a number of factors including construction

sites not obeying safety rules and regulations, narrow roadways, poor visibility, and most importantly inattentiveness of the driver and/or worker in addition to failure of the driver to obey traffic laws (e.g. Dingus et al., 1998; Bryden and Andrew, 2000). In particular, rear-end collisions occur at a higher rate in work zones and other areas with increased traffic congestion and speed variability (e.g., Meng and Weng, 2011). The presence of workers in a work zone may not only put workers at risk (as described above), but also drivers who may choose to attend to the activities of workers rather than to the forward roadway. Work zone accidents are often more severe in the overnight hours (Ebrahim, 2008) as working at night in a work zone is five times more hazardous than working during the day (Arditi et al., 2007).

Dynamic message signs (DMS) have been shown to effectively influence driver behavior (e.g. Dudek, 2004; Jones and Thompson, 2003; Hassan et al., 2012; Strawderman et al., 2013). However, in order for the signs to effectively influence speed reduction and compliance in work zones, the signs must draw the attention of the driver, the driver should be able to comprehend the message of the sign, and the driver must decide to obey the posted speed limit. Drivers' ability to comprehend the message of the sign depends on their workload. However, from a sign design point of view, the message of the sign should be able to efficiently communicate the existence of hazards in and around the

* Corresponding author.

E-mail address: mahmudur.rahman87@gmail.com (M.M. Rahman).

construction sites and allow enough time for the drivers to process the message.

The current project investigates the use of dynamic message signs as a means of increasing driver compliance with posted traffic laws, with reduced construction worker injuries and fatalities being the critical objective. The aim was to determine the impact of sign content, frame refresh rate, and sign placement on driver behavior in work zones. It is expected that the following signs will be more effective: a) signs that mention the presence of construction workers, b) signs with moderate refresh rates, and c) signs placed farther from the start of the work zone. It is also hypothesized that some people will change lanes from the right (for work zones that are off the right shoulder and vice versa) to the left lane to avoid the work zone, rather than reduce speed. Each of these hypotheses was tested in a project using a high-fidelity driving simulator with an integrated eye tracking system. In addition, a small field study was also completed to obtain real-world data for comparison to the simulation results.

2. Background

The topic of road construction work zone safety has been the focus of many studies and review papers (e.g., Kramer, 2015; Yang et al., 2015). A variety of interventions have been proposed to improve safety in work zones, including public awareness campaigns (Bergmann, 2015), worker education (Debnath et al., 2015), law enforcement presence (Zhang et al., 2014), connected vehicles and smart communication (Genders and Razavi, 2015; Rahman et al., 2015), and enhanced infrastructure and signage (Sommers and McAvoy, 2013). Dynamic message signage (DMS, also called variable message signage, VMS) is one intervention that has been used to effectively provide information regarding various road conditions and associated hazards. Dynamic information about incidents tends to be more effective than static information in drivers' diversion decisions, and that information content is very important for drivers making travel decisions (Schofer et al., 1993). Early research on the effectiveness of DMS for improving driver compliance was not promising. According to Richards et al. (1985), DMS led to drivers reducing speed 7% of the time, compared to flagging (19%) and law enforcement (18%). In addition, studies found that reading time for DMS is higher than for traditional static signs because motorists see static signs regularly (Dudek, 2004). There is uniformity for traditional static signs whereas, for DMS, the motorist must read the entire message displayed on the DMS in order to understand the message (Dudek, 2004; Jones and Thompson, 2003). These results suggested the need to improve DMS design to increase driver compliance in work zones. Specific design guidelines have been developed based on the limits of driver perception, including limits on the number of words (Dudek, 2002), amount of information (Dudek, 2004), and font color (e.g. Yang et al., 2005). With the incorporation of guidelines for DMS design, DMS have been shown to improve driver comprehension of information (Charlton, 2006), even though it requires drivers to spend more time reading the information (Erke et al., 2007). Among other factors, gender, age, road type, visibility condition, and familiarity with DMS were also found to be significant factors affecting speed reduction in work zones (Hassan et al., 2012).

Research in sign content and sign design (Lai, 2010; Purduski and Rys, 1999) has been effectively applied to work zone settings. The information content has been shown to impact driver speed reduction at work zones. Messina et al. (2012) found that drivers prefer text messages on a DMS, but graphic messages were more effective in terms of response time and accuracy. Studies have demonstrated that short, direct messages are best for DMS communication (Mattox et al., 2007; Proffitt and Wade, 1998), and that symbols (such as the "man working" figure) are also effective (Ullman et al., 2012). However, limited work has been done on how information content on signs impacts driver's attention to construction workers.

The effect of message alternating and message flashing has also been

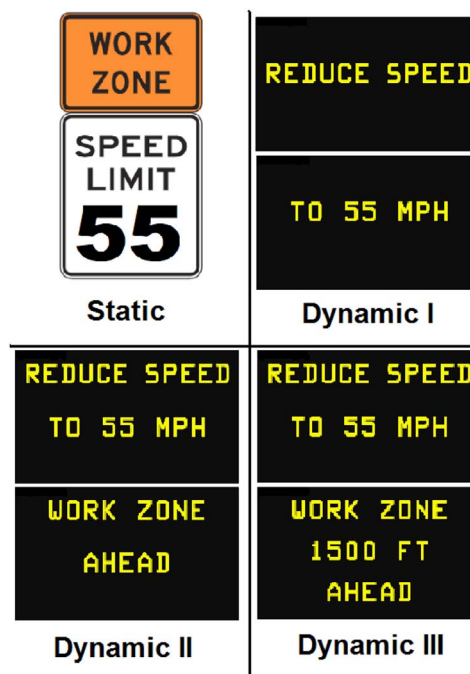


Fig. 1. Sign Types from Previous Study.

studied. Dudek and Ullman (2002) suggested that a one-frame DMS message should not be flashed. In a two-frame message situation, Dudek et al. (1981) recommend that messages displayed at two sec/frame and four sec/frame. The two-second time window is designed to allow drivers to see the message twice within the viewing distance. Some studies, however suggested that messages should be alternated at least 3 s/frame to accommodate older drivers (Staplin et al., 2001). Sign placement research has indicated that a placement distance of 1000 feet upstream from the incident or work zone was more effective than a placement distance of 200 feet (Mattox et al., 2007).

Strawderman et al. (2013) investigated the impact of sign type and sign placement on driver behavior when approaching highway work zones. Four types of signs (see Fig. 1) and three placement distances (1000, 1500, 2000 feet) were tested using a driving simulator. Results indicated that speed reduction was significantly impacted by sign type. The largest speed reduction was apparent for Static and Dynamic II signs (Fig. 1). As observed in Mattox et al. (2007), the placement of the speed reduction signs also impacted driver behavior, with greater placement distances being associated with higher speed reduction and compliance rates. The Strawderman et al. (2013) results indicated that drivers began to reduce their speed when they pass the 'work zone ahead' sign with the most dramatic speed reduction taking place after passing the speed reduction sign. However, even though their speed was reduced overall, participants failed to reduce their speed sufficiently to be compliant with the work zone speed limit of 55 mph.

3. Methods

This section describes the methods of this study in two subsections: Section 3.1 explains methods related to the driving simulator study and Section 3.2 explains the methods related to the field study.

3.1. Driving simulator study methods

3.1.1. Participants

A total of 50 participants were recruited to participate in the experiment. Out of these participants, 1 participant (female, 60 years old) could not complete the experiment due to simulator sickness and 5 participants (4 male and 1 female, 18–60 years old) could not complete

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