Transportation Research Part C 48 (2014) 311–321

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Effectiveness of graphic-aided portable changeable message signs in reducing vehicle speeds in highway work zones

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ARTICLE INFO

Article history:
Received 2 June 2014
Received in revised form 15 September 2014
Accepted 15 September 2014

Keywords:
Highway
PCMS
Safety
Speed
Vehicle
Work zone

ABSTRACT

Portable changeable message signs (PCMSs) have been employed in highway work zones as a temporary traffic control device for decades in the United States. Results of previous research showed that the traditional text-based PCMS had several limitations, such as having a short range of legibility and being difficult to read by elderly and non-English-speaking drivers. A few simulation studies indicated that using graphic-aided PCMSs could likely overcome these limitations. This paper presents the results of field experiments that were conducted to determine the effectiveness of graphic-aided PCMS in reducing vehicle speeds in the upstream of highway work zones. In field experiment Phase I, a full-matrix PCMS was programmed to display a work zone graphic and a flagger graphic, which were similar to the W21-1 sign and W20-7 sign, respectively, specified by the Manual on Uniform Traffic Control Devices. In field experiment Phase II, the PCMS was programmed to display two alternative work zone graphics along with the original work zone graphic. 1115 and 1600 valid vehicle speed data were collected during field experiments Phase I and Phase II, respectively. The results of data analysis suggested that graphic-aided PCMSs reduced mean vehicle speeds between 13% and 17% in the upstream of a work zone. This study provided valuable knowledge to government agencies and the transportation industry on how to regulate and implement graphic-aided PCMS in highway work zones.

1. Introduction

The aging U.S. highway system has led to an increasing number of highway work zones in recent years, which inevitably disrupt regular traffic flows, result in traffic delays, and lead to safety concerns (Federal Highway Administration (FHWA), 2010). According to the National Highway Traffic Safety Administration (NHTSA), the number of annual work zone fatalities has increased by about 34% in the past decade compared with the number of annual fatalities from 1982 to 1999 (NHTSA, 2012). To improve highway work zone safety, government agencies, the transportation industry, and interested individuals have conducted numerous studies on various work zone temporary traffic control (TTC) methods and devices, one of which is the portable changeable message sign (PCMS). A PCMS is an innovative TTC device which is capable of displaying a variety of messages to inform motorists of unusual driving conditions (FHWA, 2003).

The traditional type of PCMS is text-based and has been in use for decades. Many recent studies (Nsour, 1997; Wang et al., 2007; Ullman et al., 2009), however, pointed out that using text messages on PCMS has several limitations, such as confusing

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http://dx.doi.org/10.1016/j.trc.2014.09.007
0968-090X/

drivers and delaying their response during driving, being difficult to read by elderly drivers and non-English-speaking drivers, difficult to see under adverse viewing conditions, and having a short range of legibility. As sign technology advances, the full-matrix PCMS has made it possible to display graphics to drivers. Graphic-aided messages on PCMSs could likely overcome some of these limitations, particularly in complicated driving conditions such as work zones (Ullman et al., 2009). Although the advantages of graphic-aided messages were realized, their use on PCMS is still new in the U.S., and only a handful of studies have been conducted (Riemersma et al., 1982; Knoblauch et al., 1995; Luoma and Rama, 2001; Lerner et al., 2004; Wang et al., 2007; Ullman et al., 2009). Most of these studies were conducted using driving simulators in laboratory environments. Thus, there is a need to determine the effectiveness of graphic-aided PCMS in the real-world driving conditions. This paper presents the results of field experiments that were conducted to determine the effectiveness of graphic-aided PCMS in reducing vehicle speeds in the upstream of highway work zones. The results of this study could provide valuable information for the government agencies, the transportation industry, and construction companies on how to regulate and implement graphic-aided PCMS in highway work zones.

2. Literature review

Research on the advantages of graphic messages over text messages started as early as in the 1970s, and it was generally agreed that graphics could offer potential advantages because drivers could read and understand well-designed graphics quicker and farther in the upstream of a sign. Ullman et al. (2009) summarized the advantages of graphics from the results of some earliest field and laboratory experiments:

- More legible on a given size of sign and at shorter exposure durations.
- More easily recognizable under adverse viewing conditions.
- More quickly extracted by drivers when concentrating on driving; and
- More interpretable to drivers having difficulty understanding text.

Several early studies in the 1980s and 1990s evaluated the graphics adapted from European static sign symbols. Riemersma et al. (1982) discovered that the graphics for roadwork, congestion, slippery road, and two-way traffic were highly recognized, and the graphics for crash, skidding danger and reduced visibility due to rain or snow were less acceptable. Knoblauch et al. (1995) evaluated the effectiveness of graphics used on a PCMS for congestion and reduced lanes, and found that most drivers correctly interpreted these two graphics during daylight conditions within 400 ft, but less than half could correctly interpret the graphics from more than 570 ft. In addition, Luoma and Rama (2001) evaluated drivers' understanding of graphics and concluded that graphics for slippery road, congestion, and crash were most understood in European countries.

Lerner et al. (2004) compared the status of application and guidance of changeable message signs (CMSs) between the U.S. and other countries in 2004. It was revealed that while Japan and Australia had used color and Europe had applied animation in some demonstration projects, CMS messages in the U.S. were predominantly alphanumeric texts rather than graphics, and that the capability of full-matrix CMSs to display graphics, animations and color was not well-considered or well-exploited.

In the recent decade, with the help of advanced technology, many researchers have employed driving simulators to study drivers' responses to graphics on PCMSs in laboratory environments. Wang et al. (2007) assessed the effects of adding graphics to CMSs using questionnaires and a driving simulator. The results indicated that most people preferred graphics to text messages, and responded to graphics significantly faster than text messages, particularly for elderly drivers. It was also discovered that adding graphics to CMSs improved non- English-speaking drivers' understanding and responses much more noticeably than English-speaking drivers. Ullman et al. (2009) studied drivers' understanding of the work zone graphic using laboratory instruments, and revealed that while both text and symbol representations of roadwork were well understood by over 80% of the participants, the roadwork symbol was better understood than text by the Spanish-speaking participants.

3. Objectives and methodology

Most of the previous studies on graphic-aided PCMSs were conducted using driving simulators in laboratory environments, and therefore, the results only provided subjects' message reading performance in optimal circumstances. In the real-world driving situation, on the other hand, drivers have to pay attention to many other tasks, such as lane keeping, speed controlling, and car following. To overcome the limitations of simulation studies, this study used field experiments to determine the effectiveness of graphic-aided PCMS in reducing vehicle speeds in the upstream of one-lane two-way rural highway work zones.

In this paper, a text PCMS refers to a PCMS that displays only text messages, and a graphic-aided PCMS refers to a PCMS that can display graphics. A graphic-aided PCMS is further categorized into two types: a text-graphic PCMS that displays both text messages and graphics, and a graphic PCMS that displays only graphics. The primary objectives of this study were: (1) to compare the mean speed reduction rates resulted from using text PCMS, text-graphic PCMS, and graphic PCMS in the