Applied Ergonomics 52 (2016) 253–264

Contents lists available at ScienceDirect

Applied Ergonomics

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

Variable Message Signs for road tunnel emergency evacuations

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ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form
23 June 2015
Accepted 29 July 2015
Available online xxx

Keywords:
Emergency evacuation
Variable Message Sign
Tunnel evacuation
Theory of Affordances
Way-finding
Notification
System design

ABSTRACT

This paper investigates the design of Variable Message Signs (VMS) as a way-finding aid for road tunnel emergency evacuations. The use of the Theory of Affordances is suggested to provide recommendations on the design of VMS. A preliminary evaluation of 11 selected VMS systems was performed and 6 of them were further evaluated using an affordance-based within subject stated-preference questionnaire administered to a sample of 62 participants. Results are used to provide recommendations on the characteristics of the VMS systems, such as (1) size of the sign (large or small); (2) use of flashing lights; (3) colour scheme; (4) message coding (i.e., text, pictograms or a combination of them). The best performing VMS features for road tunnel emergency evacuation included the use of larger signs, flashing lights, the combination of emergency exit pictorial symbol in green in one panel and text in amber in the other panel.

1. Introduction

A Variable Message Sign (VMS) (also called Traffic Information Sign) is a programmable electronic panel capable of displaying different types of messages. Depending on the type of technology employed, the panel is capable of displaying messages composed of text, pictograms or a combination of them. Visualization technologies employed in VMS, e.g. LCD screens, include dynamic features such as the use of animation, flashing, scrolling, etc. This leads to a great flexibility in the content and type of information that can be displayed (Wang et al., 2006). This allows a great range of possibilities to the designer of the VMS. In addition, it poses several questions on the information to be displayed in order to provide understandable and effective messages (Dudek, 1991; Dudek and Ullman, 2002).

In the case of a road tunnel emergency, e.g. fire evacuation, VMS can be a useful tool to convey concise and precise information to motorists about the emergency as well as instruct them on the appropriate actions to perform to reach a place of safety, i.e. an emergency exit (Nilsson et al., 2009). In fact, VMS can be used as a procedural measure (providing real-time information/instructions) to influence people's decision making and route choice. Nevertheless, to date, little research has been carried out on the use of VMS as a way-finding aid and notification system in the case of emergency evacuation in road tunnels.

To address this issue, dedicated research efforts are needed in order to evaluate the use of VMS for road tunnel emergency evacuations to provide information to motorists and pedestrians in case of evacuation. It should be noted that the present study refers to the design of VMS within the scope to instruct people in case of evacuation on foot (i.e. motorists or passengers leaving their vehicle and walking towards an emergency exit). Some of the concepts used to design VMS for normal operations can be applied to the design of VMS for evacuation emergencies. In order to increase the probability of identification, signs should be placed in visible and expected locations (Borowsky et al., 2008). The effectiveness of a VMS primarily depends on the design of its message and the display format (Wang et al., 2006). Key design parameters are the type of display technology (light-emitting display, light-reflecting display, etc.), height and width of the characters and symbols (Dudek, 1991; Zwahlen and Schnell, 1999), the stroke width of the characters and the type of font displayed (Dudek and Ullman, 2001). The relationship between people and a VMS can be considered as a transmission of information from the VMS to people in order to modify their behaviours (Crundall and

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http://dx.doi.org/10.1016/j.apergo.2015.07.025
0003-6870/

Underwood, 2001). For instance, Koyuncu and Amado (2008) have systematically investigated the effect of location and content on the understanding/effectivity of traffic signage.

This paper suggests and applies the Theory of Affordances (ToA) (Gibson, 1986, 1977; Hartson, 2003) as a framework to design VMS for emergency evacuations. The ToA has been used in a variety of different research fields to analyse the design of everything from climbing routes (Boschker et al., 2002) to human–computer interaction design (Hartson, 2003). It has also been used to evaluate the design of emergency exits (Sixsmith et al., 1988) and to explain the effectiveness of way-finding systems for evacuation (Nilsson, 2009). In addition, the theory has been successfully employed in fire safety research to understand individual pedestrian evacuation behaviour (Joo et al., 2013; Kim et al., 2011).

In order to identify the characteristics of the VMS selected for evaluation, a preliminary literature review has been carried out. Then the evaluation of selected VMS systems is performed in two steps. In a first step, a qualitative evaluation based on the ToA is performed and a sub-set of best VMS systems is selected. Further evaluation of the selected VMS systems is made using an affordance-based stated-preference within subject questionnaire with a sample of 62 participants. A stated-preference within subject questionnaire refers to a method in which individual respondents' statements about their preference/choices in a set of options are recorded (Hensher, 1994). Recommendations on the design of the characteristics of the VMS systems have been provided.

The present work is currently used to directly assist the design of the emergency systems in a real world tunnel project, namely the Stockholm Bypass project (Sweden), co-funded by the EU Trans-European transport network (TEN-T). Given the practical application of this paper in the tunnel engineering world and their relevance in assessing the effectiveness of VMS for road tunnel evacuation, four VMS design variables have been selected for evaluation, namely 1), the size of the sign (large or small); 2) flashing effects, 3) colour scheme, 4) message coding (i.e., text, pictograms or a combination of them). This selection has been driven by the need to investigate variables which may be dependent on the type of message to be conveyed. This refers to the cases in which literature on road signs for normal operation (i.e., not in an emergency) are not entirely applicable. In fact, it is important to note that motorists may observe the VMS either while driving their car (as in normal conditions), while stopped in a car queue or while walking on foot. In addition, the layouts of the VMSs are identified in order to correspond to designs currently used in tunnel safety engineering practice.

This paper summarises the main findings of the research conducted. A technical report of this research study is also available for tunnel safety designers (Ronchi and Nilsson, 2014).

2. Theory for VMS design

The use of the ToA to study evacuation system design has been previously investigated and applied by Sixsmith et al. (1988) and by Nilsson (2009). In the present study, this theory is used for the first time to evaluate VMS systems. In particular, the categorization of affordances based on the research studies made by Hartson (2003) is here used. In fact, Nilsson (2009) showed that in order to enable the analysis of the affordances provided to people (i.e., evacuees) by an evacuation system, it is useful to divide affordances into different categories. One possible division suggests that affordances can be divided into the following four categories: 1) Sensory affordance, 2) Cognitive affordance, 3) Physical affordance, 4) Functional affordance (Hartson, 2003).

Sensory affordance is determined in VMSs by their capability of attracting the attention of the motorists and their impact on the ability in seeing the message provided. This is associated with the location (which is constant in this study) and size of the panels, the colour in use and the type of code displayed in the sign (text, pictorial symbols, and flashing lights) and its characteristics. For instance, text provided by a visual evacuation system must be sufficiently large (Dudek, 1991) and the content of the VMS should be easy to see.

Cognitive affordance is associated with the effectiveness of the VMS in providing information that motorists can understand. This is dependent on the methodology used to provide information (text, pictorial symbols, flashing lights) and the written message design and their combination. The signs are intended to instruct people on appropriate actions (Dudek, 1991). In this case, the two required actions to perform are to turn off the engine and to reach an emergency exit on foot. The use of written messages in different languages may affect cognitive affordance in relation to the expected type of population involved. The cognitive affordances provided by a design should also take into account of the context. For example, a VMS sign during the fire in the Södra Länken tunnel in Stockholm on June 16, 2008 (Åberg et al., 2008) presented an "evacuate tunnel" written message. This sign led many motorists to drive out their car through dense smoke instead of leaving their vehicle and evacuating on foot. This is a clear example in which a message was interpreted differently than the designers had intended.

Physical affordance supports the user physically performing an action. An example can be an opening device for doors. The VMS is a sensory system which does not require a physical interaction with the object under consideration, so the study of physical affordance is not relevant to VMS.

Functional affordance is associated with the goals of the tunnel evacuees. Main people's goals include reaching a safe place overcoming possible property attachment (i.e. the reluctance to leave the vehicle) and inhibiting negative social influence (Kinateder et al., 2014a, 2014b; Ronchi, 2013). VMS systems are designed in line with the same goals. For this reason, it is argued that functional affordance can be directly derived as a consequence of the factors affecting the other affordances (sensory and cognitive in this case). High scores in functional affordance are resulting from a powerful combination of the other affordances. If a system fails in terms of one of the affordances, the functional affordance will also be low as a result of the failing of that affordance. For example, a VMS that is easy to notice (sensory), easy to read/see (sensory) and easy to understand (cognitive) will also provide appropriate functional affordance.

2.1. Size of the sign

The VMS system under consideration consists of two rectangular VMS panels conveying information to motorists and three intermediate smaller squared signs (see schematic representation in Fig. 1). The dimensions of the VMS panels have been selected in order to be a credible representation of a realistic design and they have been inspired by the design of VMS panels in a real-life project (the Stockholm Bypass project). The VMS panels have a fixed dimension of 240 × 90 cm on the opposite side of the emergency exit and two possible dimensions on the side of the emergency exit, either 240 × 90 cm or a larger size of 240 × 170 cm. In fact, two different sizes are taken into consideration in order to evaluate the impact of the sign dimension (large or small) on the effectiveness of the VMS system. The intermediate panels have fixed dimensions corresponding to 90 × 90 cm. In the case of emergency, the smaller panels show red crosses which are used to encourage people to stop their vehicles. The choice of those specific sizes and layout has