Journal of Transportation Technologies, 2016, 6, 139-147
Published Online April 2016 in SciRes. http://www.scirp.org/journal/jtts
http://dx.doi.org/10.4236/jtts.2016.63013

Drivers' Reaction of Warning Messages in Work Zone Termination Areas with Left Turn

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Received 16 February 2016; accepted 15 April 2016; published 18 April 2016

Abstract

Work-zone crashes have always drawn public attention. A number of fatalities are recorded every year nationwide within work zone areas. Most existing countermeasures have been dedicated more to the advance warning areas, transition areas, and activity areas of work zone, than the termination areas, where drivers might play less attention to safety threats. In this study, the vehicle-to-vehicle communication based left turn warning system was applied at a work zone termination area, which is immediately followed by a T-intersection. The work-zone is located on the minor road side, while left turn vehicles will be appearing from the major street through the said T-intersection. A smart phone application was designed using Android coding system to provide several types of warning messages to drivers. Corresponding scenarios were designed in a driving simulator, and 20 subjects were recruited to participate in the simulation test followed by a questionnaire survey. The subjects received a warning message when driving to the termination area of a work zone on the coming left turn vehicles. Twenty test drivers' driving speed, acceleration rates, and break reaction distance to the warning messages were studied in four different scenarios. Results show that the smartphone application has a great impact on driving behaviors, especially the female voice and the beep tone warning, which are recommended for possible field tests. Besides, the developed smartphone applications can be further updated for practical applications of similar needs.

Keywords

Left-Turn Warning Message, Drivers' Smart Advisory System (DSAS), Driving Simulator Test, Smartphone Application, Workzone Termination Area

How to cite this paper: You, B.Y., Qiao, F.X. and Yu, L. (2016) Drivers' Reaction of Warning Messages in Work Zone Termination Areas with Left Turn. *Journal of Transportation Technologies*, **6**, 139-147. http://dx.doi.org/10.4236/jtts.2016.63013

1. Introduction

A proper development and operation of highway system is able to effectively promote nationwide economy development and bring people about a great convenience to their daily lives, such as shortening travel time. To maintain and improve the performance of a highway system, many efforts have been made to the stage of roadway design, construction, and maintenance [1]. However, during a construction period for maintenance in a work zone, traffic flow operation may be significantly affected and workers become more vulnerable to injury or even fatality risks [2] [3]. Fatal crashes are recorded every day in nationwide work zones in United States [4]. According to Fatality Analysis Reporting System (FARS) in National Highway Traffic Safety Administration (NHTSA), over a thousand of fatal crashes were recorded in work zone areas the year of 2003 and 2006 in US [5]. Though the fatality number had declined obviously in recent years, there are still 609 fatal crashes recorded in work zone areas in 2012. In the 2011 and 2012, the speeding has been the dominant factor contributing to traffic crashes [6].

In 2012, 30% of fatal collisions were due to speeding-related crashes, and more than 609 fatalities occurred within a work zone area. This problem is especially significant in Texas, California and Florida [6]. In the work zone area, overspeed is a serious threat to the safety of construction workers and driver. To address the safety issue caused by overspeed in a work zone area, many speed management measures have been implemented, such as installing regulatory and advisory speed limit signs, reducing lane width, providing flagger trainings, and enhancing police enforcement. Prescott *et al.* (1990) found that constant speed limit sign had no significant effect on the vehicle speed [7]. Another study also drew the conclusion that regulatory speed limit sign had minimal impact on speed controlling [8]. In recent years, more safety countermeasures have been proposed for conflicting areas, such as a work zone area. For example, smartphone applications were developed for pedestrian's crossing within a work zone activity area, to prevent a forward collision in a work zone, and to help drivers to control their entering speeds of a work zone [9] [10]. Many similar in-vehicle drivers smart advisory systems (DSASs) were designed to improve the mobility in a work zone [11]-[14]. Nevertheless, little studies have been focused on the termination area of a work zone.

Other countermeasures such as narrowing the lane width and applying the drone radar were turned out having a great impact on lowing travel speed. However, the roadway designs and drivers' performance would be varied in different sites, which means that the drone radar or speed monitor cannot be the only factor affecting the vehicle speed in a work zone. This is another challenge for field tests. With the development of advanced technology, it is possible to provide the audio warning system through the built-in equipment inside the vehicles, which however require more innovations directly from vehicle manufacturers, and may not be directly applied to existing vehicles on road.

On the other hand, the smartphone has nowadays become more and more prevalent and multifunctional. Users could download mobile application with one-second click. Such low-cost smartphone-based applications could be developed through the software AppInventor. With the help of the smart phone applications, it is possible to test the performance of different audio warning message for possible implementation in the real world. In terms of the types of message, Fung *et al.* (2009) found that the beep sound signal is the most effective one to provide the directly stimulus to drivers while a speech message has no benefit [15]. However, a recent simulator test by Rahman *et al.* (2015) indicated that, female's voice would induce better driving performance in work zone advance warning area [16].

A typical work-zone has four segments: advance warning area, activity area, transition area and termination area. A report stated that with the analysis of the work-zone related crashes distribution in terms of segment of work zone, highway type and severity of collision, activity area was observed to be the most likely location for work zone crashes [17] [18]. That is the reason why most researchers always skip the termination area and focus their attention on other segments. However, the termination area is important as it is the downstream segment where motorists leave the work zone and prepare to diverge to more lanes. The termination area traffic sign can decrease the alertness and increase the vulnerability of drivers. In real world, some work zones located at the end of an intersection, which means that the activity area and termination area share the same segment. In this situation, drivers are likely to be involved into a special kind of hazard.

2. Research Objectives

This paper attempts to develop a smartphone application for left-turn warning system in work zone termination area. In the meantime, this paper will identify the most effective audio warning messages (e.g. beep, female voice, and male voice). In order to observe the drivers' behavior under such new warning system, a virtual driving environment was designed through a high fidelity driving simulator.

3. Scenario Design

Texas Manual on Uniform Traffic Control Devices (MUTCD) proposed couples of typical work zone types in part 6 [19]. In this study, a special kind of work zone, which is located near the approach of a T-intersection. The termination area is cut off and combined with the activity area already. When a vehicle is approaching the intersection, the eyesight of the driver is likely to be blocked by the construction equipment, which could be very dangerous for vehicles to make a left turn under this situation. In this study, all scenarios were developed based on the Application 22 in Texas MUTCD Chapter 6 [19] and a real work zone site in Dallas, Texas. The shoulder-work zone is located at the minor road of a T-intersection. The participants were required to make a left turn at this T-intersection, shown in **Figure 1**.

In **Figure 1**, the dark-color vehicle (vehicle 1) is the subjective car, which can be controlled by participants in the simulator lab; the white vehicle (vehicle 2) is a designed entity in this scenario. When a subject is at a specific location towards the target T-intersection (within the designed radius of the trigger), the relevant script will be activated. Vehicle 2 will move at a pre-designed path at a certain speed. By trial and error, we decided the speed and location of vehicle 2 and the radius of the trigger. Due to the construction vehicle, drivers couldn't see the approaching vehicle. When he/she makes a left turn, there will be a high potential of making a collision.

Every participant was required to make a left turn at the T-intersection and drive four times in four different scenarios. The first one is the baseline scenario, which has no audio warning but only the static work zone signs, which are also provided by Texas MUTCD, could be found anywhere in the real life. In the rest three scenarios, drivers will receive three different one-second audio forward-collision warning messages: female voice, male voice and beep. The female and male voice warning messages were generated by an online Natural Voices converter [20]. Three kinds of warning messages have the same message time and volume. Female and male voices were easy to figure out with a distinctive tone. The sequences of the four tests for each participant were designed before the driving tests. The baseline scenario test was always the first one took by subjective.

The posted limited speed in this design is 56 km/h (35 mph) and the work zone speed limit is 40 km/h (25 mph). The lane width is 3.7 m (12 ft). There are four important distances to be determined: (1) sign spacing distance; (2) taper length; (3) stopping sight distance; and (4) warning distance.

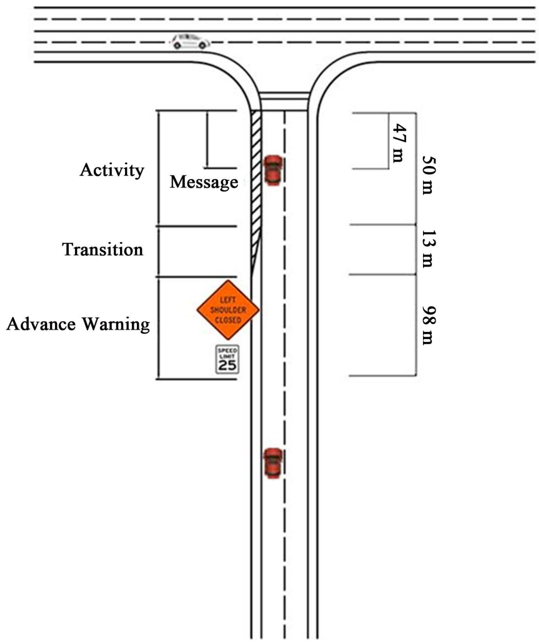

Figure 1. Layout of T-intersection with work zone.

According to the table: Suggested Advance Warning Sign Spacing from part 6 of Texas MUTCD, when the posted speed is 56 km/h, the suggested advance warning sign spacing should be 49 m (160 ft). According to the table: Merging Taper Lengths and Spacing of Channelizing Devices and **Table 1**: Taper Length Criteria for Temporary Traffic Control Zones from part 6 of Texas MUTCD, when the posted speed is 40 km/h (work zone speed), the Taper Length (L) should be 38.1 m (Equation (1)) and the shoulder taper length is 12.7 m (Equation 2).

$$L = \frac{WS^2}{60} = \frac{12 \times 25^2}{60} = 125 \text{ ft} = 38.1 \text{ m} \tag{1}$$

$$\text{Shoulder Taper Length } 0.33L = 12.7 \text{ m} \tag{2}$$

A previous study demonstrated that drivers might require an average of 2.5 sec to react to the traffic situation [21]. When the reaction time of driver is 2.5 sec, the deceleration rate needs to be 3.4 m/sec^2 (11.2 ft/sec^2) [22]. 2.5 sec reaction time was adopted in the scenario design. When the design speed is 56 km/h (*i.e.* 15.5 m/s), the brake reaction distance is 27.9 m (Equation (3)); the braking distance on level is 18.3 m (Equation (4)). So the total stopping sight distance should be 46.2 m (Equation (5)).

$$\text{Brake Reaction Distance}\left(\text{BRD}\right) = \frac{2.5 \times 25 \times 5280}{60^2} = 91.67 \text{ ft} = 27.9 \text{ m} \tag{3}$$

$$\text{Braking Distance on Level}\left(\text{BD}\right) = \frac{\left(\frac{25 \times 5280}{60^2}\right)^2}{2 \times 11.2} = 60.01 \text{ ft} = 18.3 \text{ m} \tag{4}$$

$$\text{Stopping Sight Distance} = \text{BRD} + \text{BD} = 46.2 \text{ m} \tag{5}$$

The scenario design for the driving simulator tests follows three steps: (1) choosing the perfectly matched tile; (2) developing the static entities and dynamic entities; and (3) setting up the location trigger. **Figure 2** is the screenshot of the scenario design.

In order to create a more realistic driving environment, a simple application called "Left-turn Warning" was developed by using the software AppInventor, which was installed in a smartphone for driving tests. In this application, we provided three different audio warning messages (beep, female voice, and male voice), and a timer for correcting the specific location where the driver received the warning sound (**Figure 3**) [23].

Figure 2. The screenshot of the designed scenario for the simulator tests.

Table 1. Taper length criteria for temporary traffic control zones.

Type of taper	Type of taper
Merging taper	At least L
Shoulder taper	At least 0.5L
Shifting taper	At least 0.33L

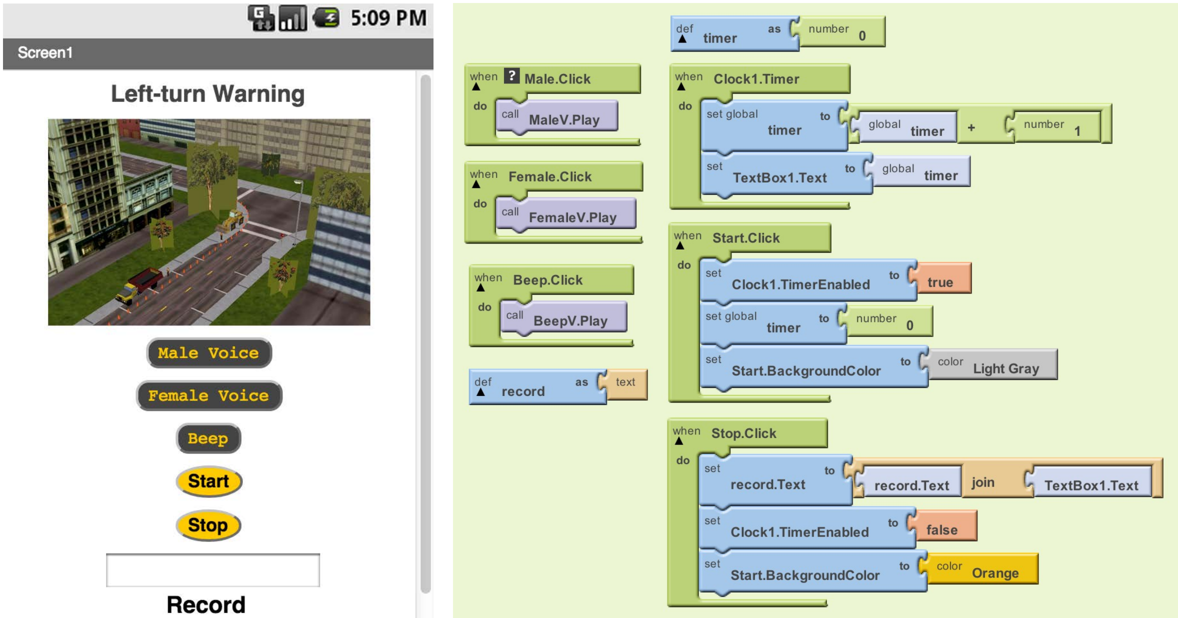

Figure 3. The designed smartphone application using AppInventor.

4. Simulator Tests and Data Collection

Twenty participants were recruited to take part in the driving simulator tests. Every participant was asked to make a left turn at the T intersection. After driving tests, participants need to fill out a questionnaire form, which includes their age, gender, occupation, and other detailed information. The demographic distribution of participants was based on the 2010 census of Houston (Table 2). As mentioned before, the sequence of scenario for each participant was picked up from a pre-designed table in order to eliminate the guess of coming scenarios by participants.

5. Performance Measures

During driving tests, the 1/60-secdata log were recorded, which was in chronological orders. The recorded information from driving simulator included time, speed, acceleration, brake, subjective X, subjective Y, and collision information. With a self-designed program in MATLAB using the interpolation function, the evenly distributed records along time axis (the 1/60 sec data sets) were converted into evenly distributed ones along distance axis (*i.e.* meter by meter data sets). These are basic information for drivers' performance measures.

5.1. Indexes of Performance Measures

Average speed, brake reaction distance, acceleration rate, and collision observations are major indexes to measure the performance in this research. Average speed and acceleration rate of 20 participants could show, to a degree, the drivers' driving behavior. When driver tapped the gas pedal or applied the brakes, the acceleration rate should be positive or negative and the average speed tends to have an increase or decrease. In terms of the brake reaction distance, the higher reaction distance and shorter reaction time means more safety with a lower potential of collision. In some scenarios, collision could be observed during the tests, which can also be included into the measurement of driving performances.

5.2. Mean Speed

The average speeds from 20 participants who have conducted the four-scenario tests were used to measure the performance of three different audio warning messages. The variation of average speeds and accelerations in the curve diagram of speed tells the driving behavior of drivers. Drivers applied brakes and accelerators in different situation. For example, when driver faces a forward collision, they are likely to slam on brakes and the speed

Table 2. Participants of tests based on 2010 Houston demographics.

Gender		Education background		Age			Driving experiences			
Male	Female	High school	Bachelor+	18 - 24	25 - 65	65+	Inexperienced		Experienced	
50%	50%	70%	30%	20%	70%	10%	Less than 1 year	1 - 2 years	2 - 30 years	30+ years
10	10	14	6	4	14	2	2	4	12	2

will reduce significantly with the high deceleration. With the help of audio warning massage, the differences of the average speed means the impact and performance of this warning system. The high speed means "dangerous" while the lower speed provides much more safety [24]. **Figure 4** shows the mean speed for all tests.

In the paired *t*-tests for mean speed of four scenarios, the statistical difference between baseline scenario and audio warning scenarios (beep, female and male) was significant (between baseline scenario and female voice scenario, p values = 8.53E−69. However, the significances test also showed no significant difference between female voice scenario and beep sound scenario (p values = 0.451).

5.3. Acceleration Rates

In real world driving, drivers need a certain reaction time to apply the brakes when they are facing to some special situations, for example, when they see a pedestrian crossing the road. For all four scenarios in this study, when subjective was approaching the work zone area, most drivers applied brakes once they have perceived the 40 km/h speed limited sign. When approaching the T-intersection, some participants tapped the brakes while others didn't. **Figure 5** shows the mean acceleration of 20 participants. In the acceleration curve of who applied brakes twice, the deceleration curve has two peaks. Most drivers tapped the brake when they received the warning message, which provide a second-time brake and a lower speed. But most drivers only applied the brakes for one time, which happened when their locations are near the work zone area.

5.4. Brake Reaction Distance

The brake reaction time designed in this study was 2.5 sec. With the analysis of brake reaction distance and braking reaction time, in one hand the designed value of 2.5 sec could be examined. A higher brake reaction distance and a longer reaction time increase the possibility of crashes. **Figure 6** shows the mean brake reaction distance and brake reaction distance from 19 participants. One out of the 20 participants has an abnormal curve (during the driving tests, this driver showed emotionally intense and felt kind of dizzy when driving), the record from this participant was deleted from analyses.

In **Figure 6**, the audio warning system has a great impact on brake reaction distance as such distance was reduced from 30.85 m to 16.39 m, 16.90 m, and 17.65 m for beep sound, female voice, and male voice, respectively.

5.5. Collision Observations

In the baseline scenario with no any audio message provided, eight participants failed to slow down when approaching the intersection, and finally hit the crossing vehicle from left. They all were inexperienced drivers. With the audio warning system, only one participant hit the crossing vehicle. We also found that, the audio warning message has a great impact on inexperienced drivers rather than experienced drivers from the mean speed profile and brake reaction distance graph of each participant.

6. Questionnaire Analyses

Through the posterior questionnaire survey to all participants, 47% of participants thought the audio warning system added the workload but acceptable while 53% of them not. All the participants though the female voice message was helpful. In the favorite messages' vote, female voice got 18 votes. The beep sound and male voice only gained one vote from the questionnaire survey. Most of drivers who took part in these tests paid more attention to the traffic sign and 65% of participants want to apply this audio warning system in their vehicles.

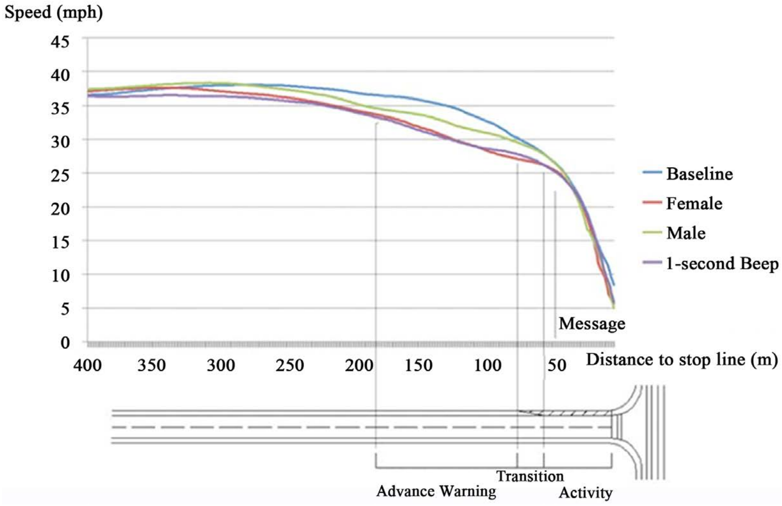

Figure 4. The mean speed of 20 participants.

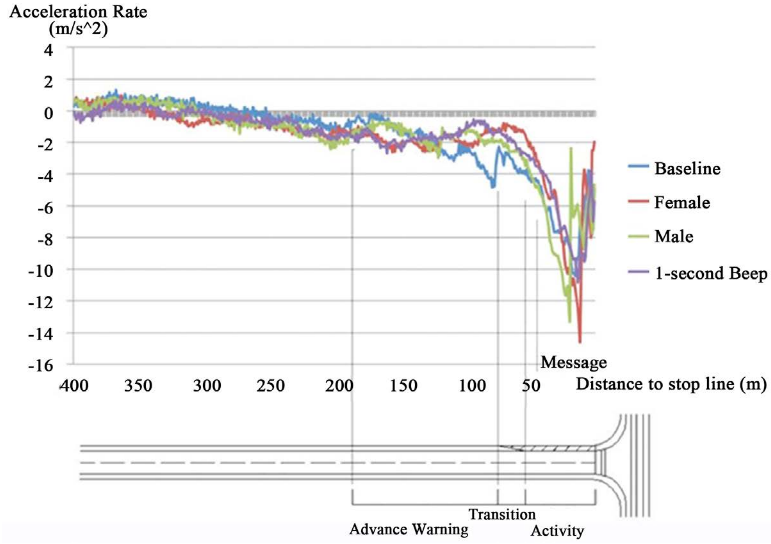

Figure 5. The mean acceleration of 20 participants.

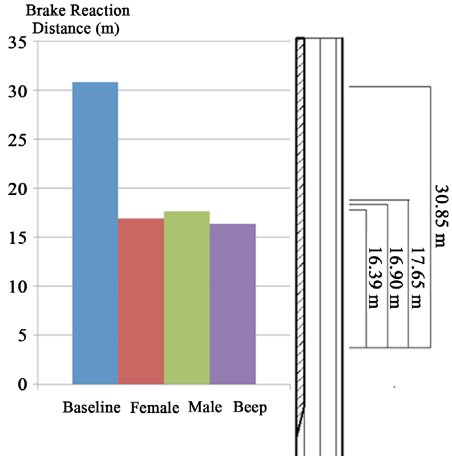

Figure 6. Mean brake reaction distance from participants' performance.

7. Conclusion

In this research, a smartphone based left turn warning message application was developed and tested in the driving simulator. Performance measure analyses indicate that, such smartphone application does have a great impact on driving behaviors. The mean speed and the mean brake reaction distance in work zone area reduced with the audio warning system. The female voice and one-second-beep warning have the best performance in this study than the male voice. Apparently, a speech message could bring kind of side effects such as the distraction to drivers' attention. Nevertheless, the questionnaire results did not reflect such concern from the recruited subjects. Collision observations also indicated that, the developed audio message may have the potential to reduce collisions with left turn vehicle. In the questionnaire survey, most drivers preferred human voices from either male or female. However, the measures of participants' driving information implied that, the beep sound and female's voice would induce better performances.

Acknowledgements

The authors acknowledge that this research is supported in part by the United States Tier 1 University Transportation Center TranLIVE # DTRT12GUTC17/ KLK900-SB-003, and the National Science Foundation (NSF) under grants #1137732. The opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the funding agencies.

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