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USE OF ADVANCED TRAFFIC SIGNAL STATUS WARNING SYSTEMS FOR

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USE OF ADVANCED TRAFFIC SIGNAL STATUS WARNING SYSTEMS FOR IMPROVING INTERSECTION SAFETY

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ABSTRACT

Signalized intersections are one of the most complicated and risky locations in the transportation network. If drivers make misjudgments and run a red light by mistake, it may put themselves and other road users at a great risk. To assist drivers in making the right decisions when passing through a signalized intersection, two Advanced Traffic Signal Status Warning Systems (ATSSWSs), i.e., the Variable Message Sign-based (VMS-based) warning system and the Vehicle to Infrastructure-based (V2I-based) onboard driver warning system, were designed and tested by driving simulator-based experiments. The results indicated that ATSSWSs significantly reduced vehicles' maximum deceleration rates, the number of red-light violations, and other critical events associated with vehicles passing through signalized intersections. The V2I-based onboard driver warning system provided more significant improvements than the VMS-based warning system in most cases. In addition, after the studied was conducted, the drivers who participated were surveyed to obtain their feedback on the two ATSSWSs. Most of the drivers indicated that the two ATSSWSs were easy to accommodate and were helpful.

Keywords: traffic signal status, ATSSWS, VMS, V2I, driving simulator, intersection safety.

INTRODUCTION

Traffic signals are intended to reduce conflicts among roadway users at intersections, and they have an important role in improving traffic safety. However, intersections are considered to be one of the most complex locations because they have numerous points at which conflicts can occur between different types of road users moving in different directions. In such a complex setting, drivers can make misjudgments and run through a red light by mistake, which puts them and other road users at great risk for an accident. In addition, in the approach to intersections, there are dilemma zones in which drivers often find it difficult to make stop-or-go decisions (Lum, 2006). This may cause hard braking, red light violations, and possible collisions. To improve the safety at signalized intersections, traffic engineers are developing new solutions based on some emerging technologies.

With the development of intelligent transportation systems (ITSs), many collision warning systems have been developed and used extensively to prevent various types of traffic crashes, such as run-off-road crashes, lane-change crashes, and work-zone crashes. Previous studies have indicated that collision warning systems are very beneficial in reducing the occurrence of crashes and improving the operational efficiency of intersections (Qi, 2009; Fung, 2007) However, few of these warning systems inform drivers of the status of the traffic signals at intersections and advise drivers concerning the safe speeds required to enter and pass through intersections smoothly and safely. Thus, two types of ATSSWSs were designed and tested by driving simulator-based experiments. First, a VMS-based warning system was designed and positioned 50 meters in advance of the intersection to inform drivers of the number of seconds remaining for the current signal interval. Second, V2I-based onboard driver warning system was designed and placed in vehicles to provide drivers, at a distance of 250 meters in advance of the intersection, with both information about remaining seconds and advice concerning the appropriate speed required to pass through the intersection safely. It was expected that these two devices would make drivers more aware of the impending change in traffic signals so they can make appropriate stop-or-go decisions when approaching intersections. Thus, these devices can help reduce the occurrence of hard braking, red light violations, and collisions at signalized intersections.

Driving simulator-based experiments were performed to evaluate the effectiveness of the proposed ATSSWSs. Three scenarios were designed and tested, i.e., 1) a baseline scenario in which no signal status warning system was used; 2) a scenario with a VMS-based ATSSWS showing the remaining seconds of the current signal on a message board; and 3) a scenario with a V2I-based ATSSWS that informs drivers of the status of the traffic signal and provides advice concerning the appropriate speed of the vehicle using voice messages. After the simulator experiments, the drivers who participated in the tests were surveyed to get their assessments concerning the effectiveness and usefulness of these two ATSSWSs.

The results of this study showed that the application of the two proposed ATSSWSs can significantly improve the safety of intersections by reducing the incidents of running red lights and collisions at signalized intersections. The survey results also indicated that the two ATSSWSs were helpful and easy to use by the drivers.

LITERATURE REVIEW

A thorough review was conducted of previous research to investigate the effectiveness of different types of driver warning systems, including traffic signal countdown devices, warning signs in advance of intersections, and onboard warning systems intended to prevent collisions at intersections.

Traffic Signal Countdown Devices

Traffic signal countdown devices provide drivers with information concerning the time remaining for the current traffic light. Figure 1 shows the traffic signal countdown head, which is the device that is most commonly used at signalized intersections. Several researchers have studied the impact of such countdown devices on drivers' behaviors. Hongyun et al. (2009) demonstrated that signal countdown devices can improve the capacity of signalized intersections and enable drivers to better prepare and make decisions before changes occur in the status of the traffic signal. However, Pulugurtha et al. (2010) reported that there was no statistically significant decrease in vehicle-pedestrian crashes after the installation of pedestrian countdown signals.

A study conducted by Ma et al. (2010) presented an extensive investigation regarding the impacts of green signal countdown devices (GSCDs) on the safety and efficient operation of intersections. The results showed that GSCDs effectively eliminated the intersection dilemma zones by making drivers aware of the phase transition so they can make decisions earlier so that the number of red-light violations was reduced significantly.

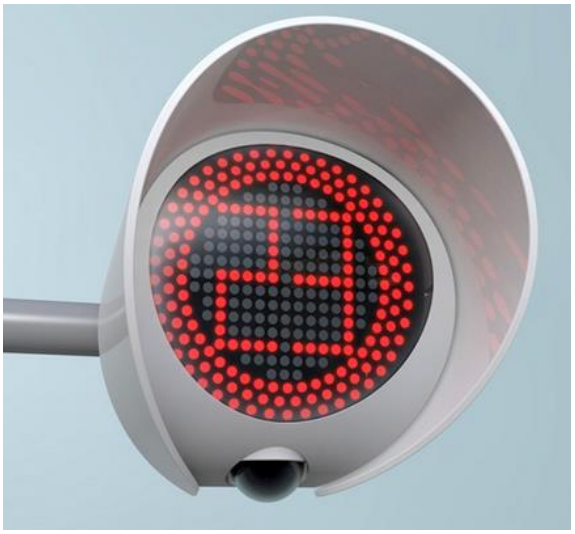

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Figure 1. Traffic signal countdown signal head

Warning Signs in Advance of Intersections

Pant and Yuhong (1995) compared approach speeds of drivers responding to four types of intersection warning signals, i.e., Continuously Flashing Symbolic Signal Ahead (CFSSA), Prepare To Stop When Flashing Sign (PTSWFS), Flashing Symbolic Signal Ahead (FSSA), and the Passive Symbolic Signal Ahead (PSSA) sign. By analyzing the speeds at which vehicles approached intersections and traffic conflicts, they found that CFSSA had the same effect as

PSSA in reducing drivers' approach speeds. Datta et al. (1982) recommended against the use of active advance warning signs because they were found to encourage drivers to accelerate at the onset of yellow in an attempt to enter the intersection before the onset of red. Sayed et al. (1999) conducted a study to evaluate the safety of advance warning flashers (AWFs) by comparing the expected accident frequencies at intersections with and without AWFs. The results indicated that intersections equipped with AWFs had fewer accidents than those without AWFs.

In Yan et al.'s (2009) study, a pavement marking countermeasure was proposed to reduce the dilemma zone and improve traffic safety at signalized intersections. It was found that the marking can contribute to a lower rate of running red lights and result in a lower deceleration rate for stopping vehicles at intersections that have higher speed limits.

Appiah et al. (2011) investigated the safety impacts of an actuated advance warning dilemma zone protection system at high-speed, signalized intersections. They found that the use of such a system reduced the rate of crashes at high-speed, signalized intersections.

V2I-based, Onboard Driver Warning System for Preventing Collisions at Intersections

Ferlis (2002) described an infrastructure-based Intelligent Transportation System (ITS) countermeasure for reducing straight crossing-path crashes at signalized intersections. He estimated that the infrastructure-based warning system could reduce straight crossing-path collisions by as much as 88% for both the violators and the victims.

Park (2012) demonstrated the results of field tests in which a cooperative intersection signal violation warning system (CISVWS) was assessed through V2I communication systems. The findings indicated that the system reduced red light violations and intersection collisions through the use of in-vehicle warning devices.

Moon et al. (2003) conducted a field test to investigate the effectiveness of in-vehicle dilemma zone warning systems at signalized intersections and concluded that the system can reduce both approach speeds and red-light violations.

Yan et al. (2015) evaluated the effect of audio-based, in-vehicle red light-running (RLR) warning messages on drivers' behaviors. The experimental results showed that the warning message decreased the rate of running red lights and the severity level of RLR crashes significantly.

Caird et al. (2008) conducted an experimental study to evaluate the safety performance of advanced, in-vehicle signs presented to older and younger drivers in a head-up display (HUD) format. It was found that the signs increased the frequency of stopping for both younger and older drivers at intersections with relatively short yellow onsets.

All of these studies indicated that various advanced warning systems can reduce the risk of accidents and improve safety. However, few of these warning systems can both inform drivers of the remaining time of the current traffic signal indication and provide speed advice, which the V2I-based onboard driver warning system proposed in this study can do. Therefore, it was important to test the proposed warning systems and evaluate their effectiveness.

EXPERIMENTAL DESIGN

In this study, driving simulator-based experiments were conducted to investigate the safety impact of applying two proposed ATSSWSs at signalized intersections. The participants' driving performances with and without ATSSWSs were collected and analyzed. After the driving test, the participants were surveyed to acquire their opinions on the effectiveness and usefulness of the two ATSSWSs.

Testing Scenarios Design

To assess the effectiveness of the two traffic signal status warning systems, three different scenarios were designed, i.e., 1) a baseline scenario; 2) a scenario with a VMS-based ATSSWS; and 3) a scenario with a V2I-based ATSSWS.

All three scenarios had the same traffic conditions, roadway geometric designs, and traffic signal control characteristics, which ensured a fair comparison. Figure 2 shows the test route with the start and terminal points. It was a four-lane roadway in a suburban area with a speed limit of 45 mph. All participants were asked to navigate through these four signalized intersections, and they arrived at these intersections with different status of traffic signal timing as follows:

- Intersection 1: at the beginning green signal interval (about 15 seconds of green time left) when the vehicle arrived at a location 250 meters in advance of the intersection;
- Intersection 2: at the end of red signal interval (about 3 seconds of red time left) when the vehicle arrived at a location 250 meters in advance of the intersection;
- Intersection 3: at the transition interval (about 3 seconds of yellow time left) when the vehicle arrived at a location 250 meters in advance of the intersection; Intersection 4: at the end of green signal interval (about 3 seconds of green time left) when the vehicle arrived at a location 250 meters in advance of the intersection.

The various designs of the traffic signal's status allowed us to test the drivers' reactions for different traffic signal conditions, and they made the experiments more realistic because traffic signal timing status is usually unpredictable in an actual traffic situation.

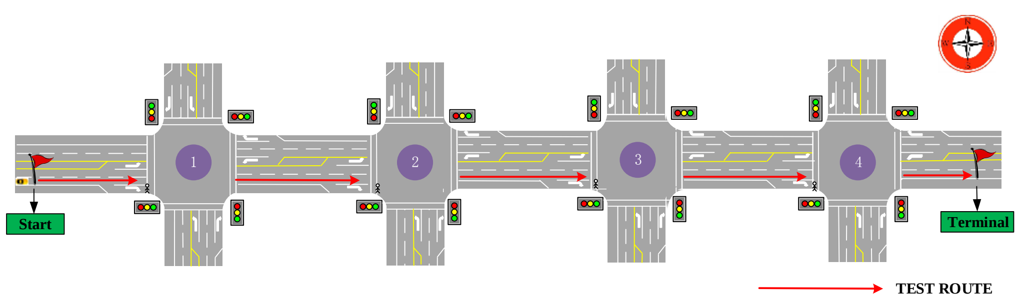


Figure 2. Design of the driving experiments

The detailed designs of these three scenarios are presented in Figure 3, and they are introduced individually as follows:

<u>Scenario 1</u>: The baseline scenario is presented in Figure 3(a). When approaching the intersection, there are no traffic warnings provided to the drivers except the static speed limit signs on the side of the road.

Scenario 2: The scenario with VMS-based ATSSWS is shown in Figure 3(b). In this scenario, a Variable Message Sign (VMS) board was set 50 meters away from the intersections on the roadside. The VMS displays a number indicating the remaining time (in seconds) of the current traffic signal light, and the color of the number (red, yellow, or green) indicates the current traffic signal status. In this study, a four-phase traffic signal timing plan was applied at all of the intersections. The signal phase sequence is the "lead-lead" sequence, which lets the two opposing left-turn phases start at the same time. The VMS countdown is only for the through direction. Thus, the green color countdown indication begins right after the left-turn phase, and it lasts until the end of the green through phase. It was followed by a 3-second transition phase with yellow color countdown indication. After that, the red color countdown indication started. As the vehicles approached the intersections, VMS showed the remaining time and the status of the current signal lights. Thus, drivers were able to make their stop-or-go decisions based on this information. For example, if a driver sees a red light when approaching an intersection and sees a red 3 on the VMS (indicating there is only 3 seconds of red light left), he will not apply the vehicle's brakes excessively to make a full stop, because he knows that the signal will turn green in three seconds, and the vehicle can pass through the intersection without stopping..

Scenario 3: The scenario with the V2I-based ATSSWS is shown in Figure 3(c). In this scenario, the vehicle is equipped with an onboard audio warning system to remind the driver of the signal's remaining seconds and provide advice concerning an appropriate speed (such "slow down" and "keep certain speed") to ensure that the vehicle can pass through the intersection smoothly and safely. The audio warnings were provided when the vehicle arrived at a location 250 meters before reaching the intersection. Different audio warnings are provided according to the approaching vehicle's speed and location, the traffic signal's status, and the presence of pedestrians in the intersection's crosswalk. For example, if the signal light is going to turn red in three seconds and the vehicle cannot pass the intersection according to its speed and the distance to the intersection, a "slow down" message is provided to the driver.

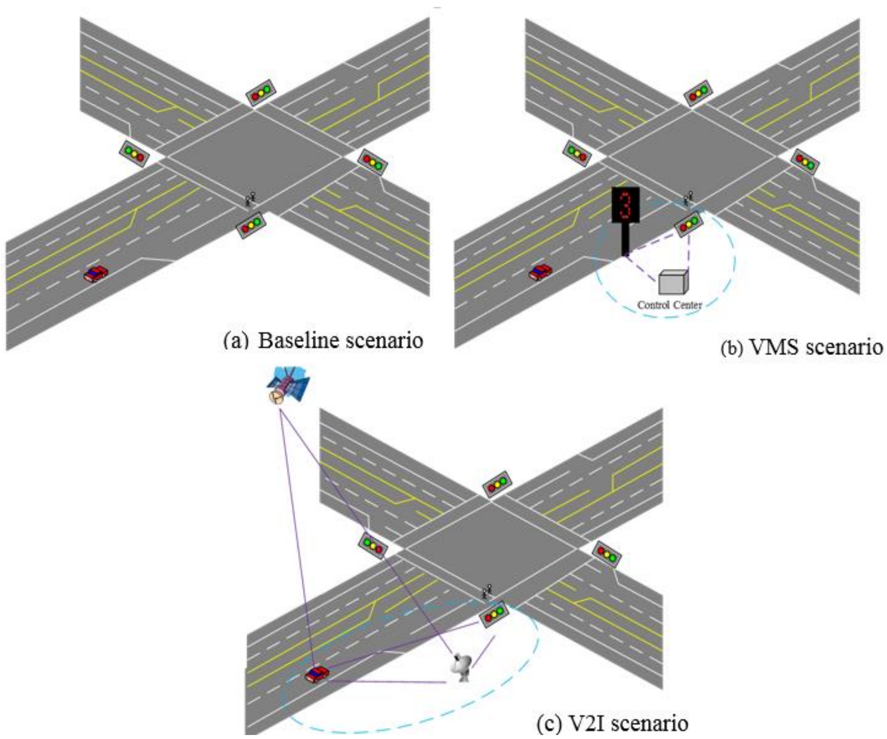


Figure 3. Design of all scenarios

Experimental Procedure

Participants

Fifty-two drivers were recruited to participate in the driving simulator experiment, including both genders and different ages and levels of driving experience. The demographic information of the participants is presented in Table 1.

Table 1. Drivers' Demographic Information

Category	Level	Drivers' Analysis	
		No. of Drivers	% of Total
Gender	Female	21	40%
	Male	31	60%
Age	Less than 24	15	29%
	25 to 44	23	44%
	45 to 54	7	13%
	55 to 64	5	10%
	65 to 75	2	4%
Driving Experience	Less than 1 year	10	19%
	1 to 3 years	16	31%
	More than 3 years	26	50%

Practice Scenario

The practice session was designed primarily to acquaint the drivers with the driving simulator. When the participants felt comfortable with the simulator, they informed the test administrator, and the actual tests were initiated.

The driving simulator at Texas Southern University is a fully integrated, high-performance, high-fidelity driving simulation system that can effectively approximate real-world driving. Drivers can easily control the steering, accelerator pedal, and brake pedal, just as they do in a real vehicle. The system has a 180-degree visual field view that was projected on three integrated screens by three separate high resolution projectors. The system is equipped with a sound system reproducing the sounds of the engine. During testing, the system can collect second-by-second driving performance data, such as travel time, distance to nearest pedestrian or vehicles, and brake rate. In addition, the system supports record and playback modes, which allow the entire test to be recorded and played back at a later time for review purposes.

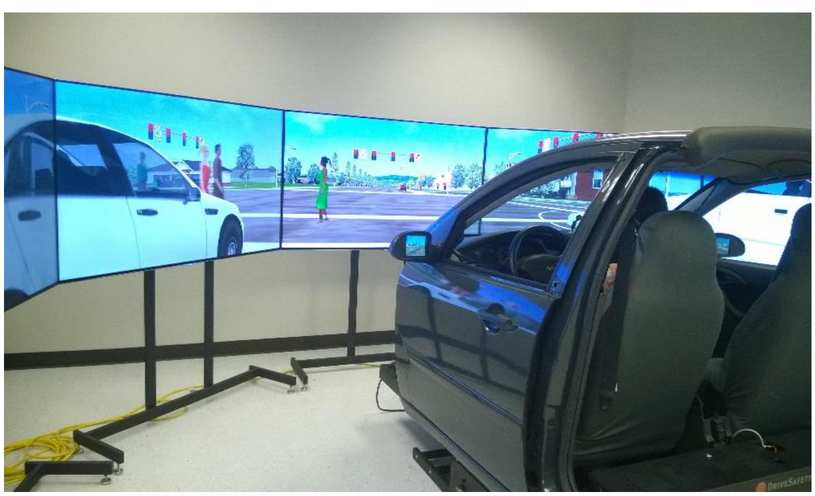


Figure 4. Driving simulator

Testing Scenario

After the practice scenarios, the testing scenarios and the two different types of driving warning systems were introduced to the participants to allow them to respond appropriately to the warning messages that they would receive during the test. Then, the participants drove through the three designed scenarios. The order of these three scenarios was decided randomly.

Post-Test Survey

A survey was conducted of the drivers who went through the driving simulation test to get their subjective evaluation results. The drivers were asked some general questions about the effectiveness and practicability of the two ATSSWSs. Overall, the survey consisted of two parts: Part I was to collect detailed information about the participants, and Part II was to collect their ratings of the safety effectiveness of the two ATSSWSs.

DATA COLLECTION

Basically, two sets of data were collected from the driving simulator-based experiments. The first set was the objective data, which was quantitative data from each test run. It served to derive the measures of effectiveness (MOE) of different types of ATSSWSs. The critical events also were identified based on the derived MOEs. The second was the subjective data, which was qualitative data from the survey after the driving test. The drivers' opinions of the two different ATSSWSs were obtained.

Measures of Effectiveness Design from Simulator-Based Experiments

To evaluate the participants' driving performance under different driving scenarios, the following measures of effectiveness (MOE) were derived based on the data collected from the driving simulator experiments: 1) maximum deceleration rate, 2) number of red light violations, 3) time to collision based critical events, and 4) pedestrian-related critical events. The following are detailed descriptions of these four types of MOEs.

Maximum Deceleration Rate

Deceleration is a good surrogate measure for safety research. It can indicate the potential severity of conflict events. Maximum deceleration measures the intensity of the braking. During the testing, the deceleration rate of the subject vehicle was recorded every second. Then, the maximum deceleration was calculated to assess the driving performance of the participants in three scenarios.

Red Light Violation-Based Critical Events

According to the FHWA information guide (FHWA 2004), one primary cause of collisions at signalized intersections is that a vehicle violates a red light and collides with road users that have the right-of-way. Therefore, the number of red light violations is another important measure of an intersection's safety performance. During the driving test, if a participant ran a red light, a red light violation-based critical event was identified.

Time to Collision (TTC)-based Critical Events

TTC is defined as the time required for the subject vehicle to have a collision with other road users, including vehicles, bicycles, and pedestrians, if they continue at their present speed and on their same paths. Basically, a lower value of TTC indicates a greater likelihood of a collision. TTC in seconds was measured between the subject vehicle and the nearest road users. In this study, when the TTC value was less than a threshold, i.e., 2 seconds as suggested by Hao et al. (2013), a critical event was identified.

Pedestrian-Related Critical Events

Pedestrian safety is a major concern at signalized intersections. The proposed ATSSWSs were designed to reduce the drivers' misjudgments at signalized intersections. As a result, they should reduce the risk to pedestrians. To measure their impact on pedestrians' safety, a specific type of pedestrian-related critical event was derived based on two criteria:

1) The driver braked hard due to the presence of pedestrians who had the right-of-way to cross the intersection.
2) The deceleration rate of the vehicle was greater than 0.5 G (4.9 m/s^2), which is equivalent to the rate for a full braking on wet pavement and is approximately the point at which skid marks begin to appear in most cases.

This critical event indicated that drivers braked hard to yield to pedestrians in the crosswalk when passing an intersection.

DATA ANALYSIS

Analysis of Drivers' Performances

Based on the data collected during the simulator testing, the four MOEs were derived. Drivers' performances in different testing scenarios were evaluated and compared based on these four MOEs. Since each participant drove through all three scenarios, the results for these three tests were related to each other by drivers. Thereby, statistical methods for paired data should be used for data analysis. In addition, since some MOEs are discrete data, a non-parametric statistical test for comparing the means of two groups of paired data, i.e., the Wilcoxon Test, was selected to compare the drivers' performances in different testing scenarios. The results of the Wilcoxon Test are presented in Table 2.

Table 2. Wilcoxon Test Evaluation Results for the Two Technologies

MOEs	Scenarios	Average of MOEs	Improved Percentage	Z-value Compared to Baseline	P-value Compared to Baseline
Maximum Deceleration *(m^2/s)*	Baseline	-6.037	na*	na*	na*
	VMS	-4.175	30.8%	-4.667[a]	2.38E-07
	V2I	-3.154	47.8%	-5.601[a]	1.87E-11
Red Light Violations *(# of Violations per Test)*	Baseline	0.289	na*	na*	na*
	VMS	0.039	86.5%	-3.357[a]	0.000445
	V2I	0	100%	-3.873[a]	3.38E-05
TTC based Critical Events *(# of Events per Test)*	Baseline	1.808	na*	na*	na*
	VMS	1.096	39.4%	-3.084[a]	0.001466
	V2I	1.192	34.1%	-2.730[a]	0.007672
Pedestrian-Related Critical Events *(# of Events per Test)*	Baseline	1.154	na*	na*	na*
	VMS	0.192	83.4%	-4.745[a]	1.6E-05
	V2I	0.135	88.3%	-4.460[a]	1.03E-05

*****na*** *means "not applicable"*

In Table 2, the MOEs from the two scenarios that use ATSSWSs were all compared with the MOEs from the baseline scenario without the ATSSWS. As shown in Table 2, all of these results indicated the same tendency, i.e., the two ATSSWSs can improve traffic safety significantly for both vehicles and pedestrians.

For the comparison of the maximum deceleration rates, it was found that both warning systems can reduce the maximum deceleration rate significantly, especially the V2I-based ATSSWS (Z = -5.601, P = 1.87E-11).

For the TTC-based critical events, it was found that the average number of TTC-based critical events in the V2I scenario was much smaller than in the baseline scenario (Z = -2.730, P = 0.007672). The VMS scenario had the lowest average number of TTC-based critical events (Z = -3.084, P = 0.001466).

The results also indicated that the VMS-based warning system can reduce the red-light violations by 86.5%, and there were no red-light violations with the V2I-based ATSSWS.

The results of the statistical analysis also showed that the pedestrian-related critical events were reduced dramatically with the two ATSSWSs. The VMS-based ATSSWS reduced the pedestrian-related critical events by as much as 83.4%, while the V2I-based ATSSWS reduced these kinds of critical events by approximately 90%.

Note that the results of driving simulator studies were related directly to the sample size and nature of the drivers. To test the sufficiency of the collected sample size, the required sample size, ***n,*** was estimated according to the following equation (Roess et al., 2011):

$$\boldsymbol{n = \frac{z^2 \sigma^2}{e^2}} \qquad \textbf{(1)}$$

where:

z = Critical value for the specified confidence interval
e = Desired margin of error
σ = Population standard deviation

Among the collected MOEs, only the “maximum deceleration” was a continuous variable, and a reasonable margin of error can be selected for it. Therefore, this MOE was used to estimate the required sample size based on a 90% confidence interval and a margin of error of 0.5 m/s^2. For different testing scenarios, drivers’ performances varied at different levels. According to the collected maximum deceleration data, the baseline scenario had largest variance (σ = 2.176), followed by the VMS scenario (σ = 1.49), and the V2I scenario (σ = 1.18). Therefore, according to Equation (1), the required sample sizes were estimated for different scenarios. They are 51 for the baseline scenario, 24 for the VMS scenario, and 15 for the V2I scenario. Since each driver drove through all three scenarios, a minimum of 51 drivers was needed for this study, and the current sample size (52 recruited drivers) was sufficient.

Analysis of Survey Results

A survey was conducted to question the subjects who participated in the driving simulator test. In the survey, the test subjects were required to evaluate the effectiveness of different messages provided by the two ATSSWSs during the test, as listed in Table 3.

Table 3. Traffic Signal Time Status Warning Messages

Type of Warning System	Warning Messages
Variable Message Sign Board	Time Countdown
In-Vehicle Driver Warning	Signal Time Warning
In-Vehicle Driver Warning	Suggested Speed Warning
In-Vehicle Driver Warning	Slow Down

The designed survey questionnaire is presented in Figure 5. The survey results were analyzed using Excel software, and they are summarized in Figure 6.

Date		
First Name	Middle Name	Last Name

What is your gender?
☐ Male ☐ Female

What is your education?
☐ High School diploma or less ☐ Undergraduate ☐ Graduate or more

Do you have a driver license?
☐ Yes ☐ No

What is your age?
☐ Under25 ☐ Between 25 to 35 ☐ Between 36 to 55 ☐ Over 56

If you have driver license, how long have you had?
☐ Less than 1 year ☐ 1 to 3 years ☐ more than 3 years

Please rate the effectiveness of the two advanced traffic signal status warning systems (ATSSTWS) messages.

Traffic Signal Status Warning System		Extremely Helpful	Very Helpful	Helpful	A Little Helpful	Not Helpful At All
Variable Message Signs		☐	☐	☐	☐	☐
V2I Based Warning Message	Signal Warning	☐	☐	☐	☐	☐
	Suggested Speed Warning	☐	☐	☐	☐	☐
	Slow Down	☐	☐	☐	☐	☐

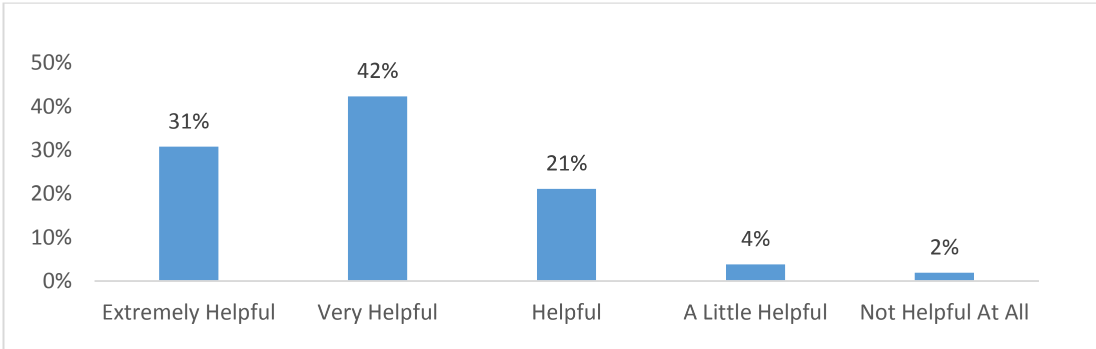
Q1: In your opinion, how much is driving in simulator different from your real-world driving experience?
☐ Very different ☐ Different ☐ A little different ☐ Similar ☐ Very Similar

Q2: Are you used to the warning system?
☐ No, it's hard for people to accommodate
☐ Yes, but it will take some time
☐ Yes, it is easily for people to accommodate

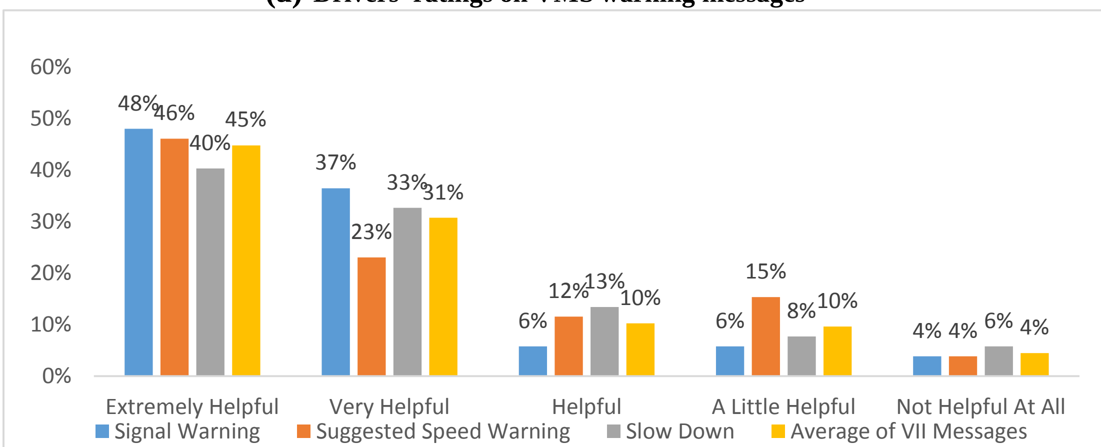
Q3: Which type of warning advice do you prefer?
☐ Voice warning ☐ Variable Message Signs

More recommendations and comments
If you have any comment or recommendation, please write it down.

Figure 5. Survey Questionnaire



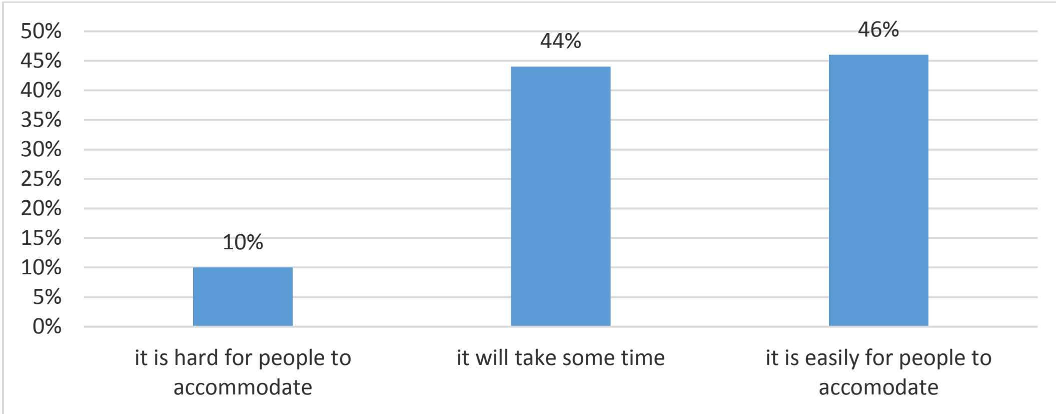
(a) Drivers' ratings on VMS warning messages



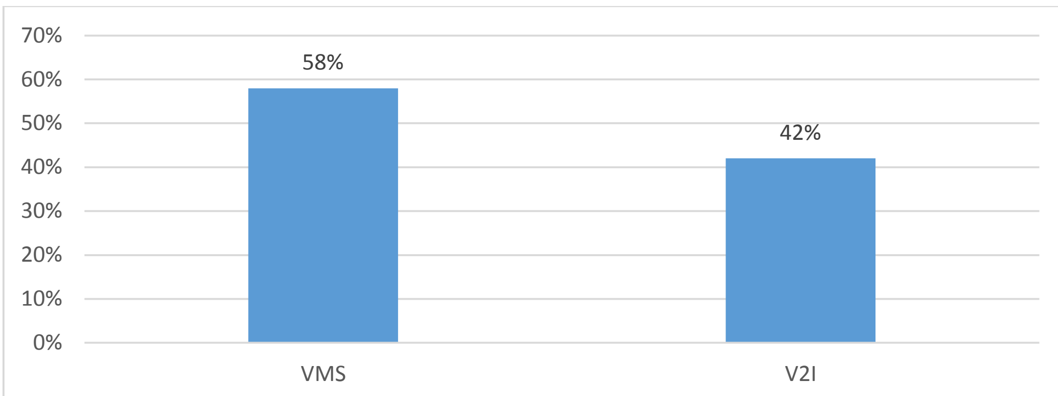
(b) Drivers' ratings on V2I-based warning messages

Figure 6. Drivers' ratings of the messages provided by the two ATSSWSs

Figure 6(a) shows that 94% of the participants stated that the VMS-based ATSSWS was helpful. It can be concluded that most drivers believed that they would benefit from the use of VMS-based ATSSWS. The results in Figure 6(b) show that 90% of the participants stated that the signal warning messages from the V2I-based ATSSWS were better than the level of "helpful;" 81% of participants said that the suggested speed warning message was helpful; 86% of participants said the "slow down" warning message was helpful. An average of 86% of participants believed that the V2I warning messages were helpful.



(a) Drivers' acceptance of two warning systems



(b) Preference of the two warning systems

Figure 7. Drivers' acceptance of and preference for the two warning systems

According to the survey results in Figure 7(a), only 10% of the participants stated that the two traffic signal status warning systems were hard for people to use; 46% of the participants said that the two ATSSWSs were easy for people to use; and 44% of the participants stated that it would take some time for them to get used to the systems. Overall, 90% of the participants believed that they were able to adjust to the two proposed ATSSWSs effectively. Therefore, it can be concluded that the two ATSSWSs would be acceptable to most drivers. In addition, the survey results in Figure 7(b) indicated that more drivers favored the VMS-based warning system over the V2I-based warning system.

CONCLUSIONS AND FUTURE WORK

In this study, the safety impacts of two different types of ATSSWSs were investigated by driving simulator-based experiments, and a survey was conducted of the participants to get their feedback on these two warning systems. The key findings from this study were:

1) Use of both proposed ATSSWSs will improve the traffic safety at signalized intersections by reducing the chance of hard braking, red light violations, pedestrian-related critical events, and traffic collisions.

2) Between the two types of ATSSWSs, the effectiveness of the V2I-based ATSSWS was more remarkable than that of the VMS-based ATSSWS. However in the survey, more participants preferred to use the VMS-based warning system.
3) Most drivers believed that the two ATSSWSs were helpful and easy to adjust to.

Note that the use of VMS-based ATSSWSs may cause a diversion of the driver's attention while driving. To investigate this problem and its potential safety impacts, in a future study, an eye-tracking device could be used during the simulator experiment to determine the average time that the drivers looked at the VMS-based ATSSWS. In addition, to better evaluate its impacts on the pedestrian safety, the countdown pedestrian signal indications also could be included in the expermental designs of future study. This research was conducted based on the driving simulator-based experiments. In the future, field study should be conducted to further verify and improve the results of this study.

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