Examining the Effects of Augmented Reality Traffic Signs on Driver’s Performance and Distraction

By
Iman Farhat

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EXECUTIVE SUMMARY

Driving is a complex task that requires full attention and awareness on the road. While traversing roadways, drivers need to be fully attentive by scanning the environment and gathering as many important informational inputs as possible. Driving has three main levels: control, guidance and navigation. Control includes steering and speed control. Guidance can be defined as path following in response to road characteristics and traffic conditions. Whereas navigation comprises trip planning and route adjustments. Those levels differ based on complexity and safety, with navigation being the most complex and least safe [1]. Due to the complexity of navigation, a higher demand on integrating technology in automobile industry arose to simplify this task to the driver as much as possible and increase safety. Thus, in-vehicle navigation systems have emerged and become common vehicle attributes.

As driver’s error is identified to be a causal factor in 75 - 95% of the crashes [2]–[5], the in-vehicle systems can be helpful to the driver by presenting real-time information that is needed at the right place and right time. Avoiding mistakes and violations in driving could help in drastically reducing crash rates. Since Traffic Control Devices (TCDs) are the primary form of communication with drivers, integrating TCDs in the automobile system would be a significant step towards safer and more efficient roadway systems. Taking the in-vehicle systems a step further, Head-up displays (HUD) were introduced to provide drivers with a wider variety of information presented in their line of sight. Those systems comprise a wide range of navigation and warning displays.

With the fast pace of automobile technological advancements, augmented reality head-up displays (AR-HUD) were introduced and are currently under mass production [6]. It is necessary to test driver performance with any potential system that’s being integrated in automobiles before it gets released. Previous studies have shown that AR-HUD are very effective in communicating real-time necessary information with drivers [7]–[10]. They have improved driver’s performance and compliance with rules and regulations. In addition, AR-HUD was proven to be very beneficial in directing driver’s attention and hazard detection. But the question remains: what if the driver receives multiple cues at the same time internally and externally? Would AR-HUD be associated with any sort of distraction?

The objective of this research was to examine the effect of AR-HUD traffic signs on driver’s performance and distraction. In addition, the effect of different flashing rates on driver’s reaction is studied. Eighty-eight subjects between 19 and 65 years old participated in this study. Participants were asked to watch 6 different scenarios in a random order, and to respond to a leading braking vehicle by pressing a brake pedal. The leading vehicle would brake unexpectedly at the same time or a little after the AR traffic sign is displayed.

A secondary visual detection task was introduced to keep the subjects engaged. All scenarios presented regulatory and warning signs. Scenario A was a traditionally signed segment. Scenario B served as the base case, with a leading vehicle braking without any sign displayed. Scenarios C through F had AR traffic signs displayed at different flashing rates (1Hz, 2Hz and 3Hz) with concurrent or lagged braking of the leading vehicle.
Reaction times were compared between Scenario B and C to determine whether the AR signs delay driver’s reaction time to other competing cues. Scenarios D, E and F were compared to determine if reaction times would be equivalent. Lastly, reaction times in scenarios A and C were compared to indicate if there is a significant difference between environment that is traditionally signed and another with AR signs. The results of the three hypotheses tests show that AR signs do not delay driver’s reaction to other external competing cues; rather, they direct their attention to the road. Reaction time is significantly affected by the flashing rate, with the lowest perception/reaction time associated with a sign flash rate of 3 Hz. In addition, driver’s perception-reaction time in a traditionally signed environment is equivalent to that when signs are presented in the AR form.
ACKNOWLEDGEMENTS

I would first like to thank my advisor Dr. David Noyce for his mentoring and guidance during my time at the University of Wisconsin-Madison and for his continuous support and assistance throughout this project. I would like to thank Dr. Sue Ahn and Dr. Madhav Chitturi for serving on my thesis defense committee. I would also like to acknowledge the assistance and supervision of Kelvin Santiago-Chaparro and Dr. Madhav Chitturi. Thanks to my colleagues in the TOPS lab for helping me with the Beta testing of the experimental design. Thanks to SAFER-SIM and UTC for their support. Finally, I would like to thank my family and friends for always believing in me and for their constant support in every step I make throughout my whole academic years.
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1. INTRODUCTION

The 21st century is witnessing unprecedented technological innovations in consumer electronics and an automotive industry that has already begun to revolutionize the experience of driving. The most recent groundbreaking development is the emergence of self-driving or autonomous vehicles, expected to become commonplace in the near future. While current infrastructure is designed to support traditional manually operated vehicles, with communication elements of the driving environment supported by traffic control devices (TCDs), autonomous vehicles do not depend on roadside regulatory, warning or guide devices, suggesting a potential future without post-mounted traffic signs. However, the high costs of autonomous vehicles will delay mass adoption of the new technology, resulting in a timeframe in which both traditional and self-driving vehicles share the same roads. During this transitional period, the safety of drivers without autonomous vehicles is of paramount concern, necessitating the development of technology to provide a smooth infrastructure transition to universal adoption of self-driving vehicles.

Holographic augmented reality (AR) displays, which synthesize computer text and real-world images [8], represent a potential intermediary step between traditional and autonomous vehicles. This technology, which has been helping pilots in the aviation field for many years, builds on head-up displays (HUD), which are currently employed for navigation and other purposes. AR displays shift much of the responsibility of traffic control from post-mounted signs, traffic signals, and pavement markings, which currently cost the United States billions of dollars each year [11], to technology within the vehicle cabin. If standardized, this
technology would allow highway designers to develop new methods for maintaining and operating highway infrastructure.

Researchers across the world have been exploring different methods of communicating guidance and warning messages to drivers. The most recent research focuses on new automotive technologies. Some manufactures and companies, such as Continental, Navdy, Garmin, and others [6], [12], [13], have already released devices and vehicles that adopt in-vehicle HUD technology to present navigational information as well as selected warning messages. Additionally, others are in the process of testing navigational and warning systems in the form of AR displays [6], which help to direct the driver’s attention to specific road features and information by displaying interactive messages and images only when needed, a method that has been proved to be very effective in decreasing detection and response time amongst drivers of all ages and cognitive abilities [9], [10]. A previous study was conducted to explore the idea of presenting TCDs in the form of augmented-reality head-up displays (AR-HUD). It was shown that drivers comply to AR-HUD regulatory and warning traffic signs [14]. With the above in mind, there is a need for research to examine whether AR-HUD traffic signs can be associated with any sort of distraction.

1.1 Objectives

The objective of this research is to evaluate the effects of presenting TCDs in the form of AR displays on the driving task, and examine the driver’s behavior when receiving multiple concurrent cues. Specifically, this research studies the perception-reaction time of drivers to an unexpected external cue while displaying an AR-HUD regulatory or warning traffic signs.
It is also desired to determine if the flashing rate of the AR-HUD traffic signs impacts the perception-reaction time.

1.2 Organization

This report is composed of five chapters, references and appendix. Chapter 1 introduces the research along with its objectives and motivation. Chapter 2 provides a comprehensive literature review about previous studies that are relevant to this research. Chapter 3 presents the methodology followed to design, perform and analyze the experiment. Chapter 4 describes the data obtained along with the analysis and results of the study. Chapter 5 presents the conclusion of the study along with future recommendations. Chapter 6 lists the references used in the study. Chapter 7 provides an appendix that consists of figures and tables of the data collected.
2. LITERATURE REVIEW

2.1 Traffic Control Devices

Traffic control devices (TCDs) are a paramount component of the transportation infrastructure. Those devices are the means of communication between all road users and the operating infrastructure. TCDs present needed information to the road users to navigate the transportation facilities safely, efficiently and lawfully. As described in the Manual of Uniform Traffic Control Devices (MUTCD), TCDs are composed of a wide variety of pavement markings, signs and signals which communicate regulatory, warning and guidance information. Regulatory devices notify road users about regulations and traffic laws. Warning devices notify about a situation that might not be obvious to the road users. While guide devices present directions, destinations, distances, recreational information and others [15]. In addition to uniformity, “to be effective, a traffic control device should meet five basic requirements: fulfill a need, command attention, convey a clear simple meaning, command respect from road users and give adequate time for proper response” [15]. Accordingly, the design, placement, operation and maintenance of TCDs should be carefully handled. The design features of TCDs such as size, shape, color, composition, legibility…are determined based on those requirements. Devices should be placed in the road user’s view to provide adequate visibility. Also, the location and legibility should be determined in a way to provide the road user with sufficient time to perceive and react. Functional and physical maintenance should be performed on a regular basis to determine whether the devices still meet the current traffic conditions and to retain legibility and visibility.
2.2 Driver Behavior

While driver behavior cannot be predicted, it is necessary to conduct studies to examine how drivers would behave and perform in certain situations and indicate where they might err. Driver errors have been identified to be the main cause in 75 - 95% of roadway crashes [2]–[5]. However, since few research efforts dealt with identifying the types of errors, Stanton and Salmon classified the errors done by drivers when interacting with intelligent transportation systems (ITS) such as automated cruise control, navigation systems and collision warning systems [4]. The three dominating human error theories, proposed by Norman, Reason and Rasmussen, suggest that the major errors in driving take place during recognition, decision and performance phases. Recognition phase includes perception and interpretation. Some of the causes that might lead to recognition errors are failure to observe, inattention to the roadway and internal/external distractions. Decision phase includes planning and intention to initiate a response. Misjudgment, improper maneuver, and excessive speed are some of the reasons drivers might err during the decision phase. Performance phase includes initiating an action and execution. Panic and inadequate directional control are identified as causes for performance errors [16], [17].

Human errors in driving are classified into 4 categories: slips, lapses, mistakes and violations [18]. Slips and lapses are attributed to unintended attentional and memory failure respectively and thus the error occurs at the execution level. Whereas mistakes, originating at the planning level, are considered to be due to an intended action. Violations, the most complex type, occur when drivers don’t conform to rules and regulations. Violations can take two forms: unintended or deliberate [19]. Unintended violation would be, for an example, exceeding the posted speed limit if the driver missed the traffic sign. Whereas deliberate violation would be
knowingly speeding. According to a driver behavior questionnaire (DBQ) completed by 520 participants, the most frequent violation was identified to be unknowingly speeding. This suggests that the roadside signs are neither communicating efficiently with drivers nor drawing their complete attention. Not to mention that the roadway characteristics (geometry, roadside and TCDs) impact the driver behavior as well [20].

One of the most frequent slip errors is distraction or lack of attention in other terms. Previous researches have shown that lack of visual attention accounts for a big portion of road traffic crashes [21], [22]. A large percentage of road crashes are attributed to inattentive driving [23]. During the visual search for information, drivers might encounter some level of internal or external distraction that could drive their attentions away from the roadway and hinder their situational awareness, the ability to perceive and comprehend environmental elements as defined by Endsley [24].

The Traffic Operations and Safety (TOPS) Laboratory at the University of Wisconsin-Madison conducted a study with the Federal Highway Administration (FHWA) to evaluate the effect of elongated pavement markings (EPM), demonstrated in Figure 2.1, as a supplement to traditional post-mounted traffic signs [25]. Pavement marking signs may have advantage over post-mounted signs primarily due to the location of pavement marking signs in the driver’s line of sight. When compared to regular pavement markings, EPM have been shown to having a significant effect on improving the recognition distance. The results conveyed that drivers decrease their operating speeds when the regulatory and warning signs were displayed as EPM in the presence of the post-mounted signs. EPM helped improve driver compliance and safety
behavior. This was a scientific demonstration that presenting signs directly in front of the driver or in a ‘head-up’ location may lead to better observation, recognition and compliance.

Figure 2.1: Illustration of Elongated Pavement Markings (EPM) [25]

In cases where the real-time driving task is complex, it is significant to keep track of the dynamic and changing situations and factors throughout the task [26]. Along with that, understanding the human capabilities and the different types of human errors and at which level of the driving task they occur helps in finding effective ways, one of which is the AR signs, to minimize such errors. It is necessary to make sure that minimizing one type of error doesn’t lead to emergence of another.
2.3 In-vehicle Technologies

It has been a while now since manufacturers and researchers started testing the different display applications that can be integrated inside the vehicle [7], [10], [27]–[33]. The different types of display are head-down display (HDD), HUD and AR. HDD, referred to as infotainment systems, exist already in many of the vehicles that are on the roads now. HDD can really be helpful in navigation; however, it causes some distraction for drivers because they have to look down and away from the roadway to search for the information they need.

The Minnesota Department of Transportation conducted a study to evaluate the driver performance when using in-vehicle signage (IVS) displayed on a mobile device as HDD [30]. The results showed that in most of the cases, drivers complied with the speed limit whether the IVS were present or not. The response time to a roadside visual detection task increased in speed transition zones regardless of the presence or absence of IVS. The study concluded by suggesting that driver workload such as searching for information increases significantly during transitioning to a new speed zone.

HUD, as the HDD, present the needed information to driver, but instead, the information is displayed on the windshield in the driver’s line of sight. Some manufacturers, such as Continental, are supplying new vehicle models with HUD including BMW, Mercedes Benz and Audi [6]. So far, HUD has conveyed the speedometer data, navigation directions, speed limit and warnings at the specific section of the road the driver is traversing. Figure 2.2 below shows the application of the HUD.
A study was done to test driver compliance with speed limits by presenting messages in different forms of HUD on actual roadways [7]. The different forms were: a warning sign, numeric warning showing the driver’s speed along with the speed limit, and a graphical representation of the vehicle speed and speed limit. Findings showed that a HUD warning (triangular exclamation mark) sign shown in Figure 2.3 is the most effective form in reducing the time taken by the drivers to slow down to the speed limit. This sign is displayed in a dynamic manner only when the speed limit is exceeded. The display pattern was identified to a bouncing effect where the location of the sign changes vertically.
Another study examined the effects of both modes, HUD and HDD on the driver performance and psychological workload ratings in commercial vehicles [35]. The drivers were tested based on performing four different tasks: commercial goods delivery, navigation, detection and maintaining speed, and response to an urgent event. The results show that drivers performed similarly in the first task when using HUD or HDD. Whereas the response time to an urgent event was faster and the speed control was more consistent with HUD than that with HDD in both cases: low and high workload. Also, drivers showed less mental stress with HUD when the workload was low.

The most advanced technology currently on the market is the AR display that is being tested in luxury car brands illustrated in Figures 2.4 - 2.6. AR is a form of a more advanced HUD that can convey lane departure warnings, automated cruise control and blind spot monitoring. For instance, if the driver is deviating away from the lane, the vehicle will produce visual, audible and haptic alerts to warn the driver about the situation he is facing [36].
Figure 2.4: Illustration of AR-HUD Lane Departure Warning [6]

Figure 2.5: Illustration of AR-HUD Automated Cruise Control [6]
In a research performed by Schall et al., the effectiveness of AR cues in assisting cognitive impaired elderly drivers and improving their safety was evaluated [10]. Driver behavior was investigated in terms of speed-of-processing (SOP) when AR cues directed the attention of the drivers to roadside hazards compared to when they were absent. The study resulted in confirming that the detection of low visibility objects and the response time were improved. A similar study was conducted by Rusch et al. but on middle-aged drivers [9]. The evaluation of driver performance was based on the response time for detecting a potential hazard. The driver response time for detecting hazardous objects was found to decrease in the presence of AR cues.
2.4 Literature Review Summary

After conducting a thorough literature review, it was inferred that AR-HUD has a great potential in communicating needed information with the drivers at the right time and place. This promotes safer and more efficient navigation of the transportation facilities. AR-HUD, being presented in the driver’s line of sight, helps in directing driver’s attention to the road. Response time to hazards are improved when AR-HUD warn the driver about the situation ahead. In addition, AR-HUD regulatory and warning traffic signs have a similar impact as post-mounted signs on drivers’ speed compliance. However, there remains a hole in the research when it comes to evaluating the AR-HUD traffic signs, when receiving multiple internal and external competing cues at the same time.
3. RESEARCH METHODOLOGY

To address the objectives of this research, a dynamic survey was conducted, where participants watched different simulated video scenarios and responded to certain actions that are explained later in this chapter. Because perception-reaction time is an important measure of driver’s behavior, this variable is chosen as the measure of effectiveness in this experiment.

3.1 Experimental Design

As the first objective of this research is to evaluate the effects of AR-HUD traffic signs on driver’s performance and distraction, three different scenarios (A, B and C) were created. The traffic signs displayed regulatory and warning information, such as speed limit sign, curve ahead warning sign and pedestrian ahead warning sign. To study whether an AR-HUD traffic sign can distract drivers from other external cues, all scenarios had a leading vehicle that brakes unexpectedly at a random instant in the scenarios to which the subjects had to respond.

The second objective was based on previous researches that showed dynamic displays draw driver’s attention better than stationary displays [10], [37], [38]. Three different flashing rates (1Hz, 2Hz and 3Hz) were selected to be studied. The upper limit of 3 Hz is the maximum flashing rate allowable to avoid seizures [39] and also the optimal rate to convey urgency [40], [41]. While the lower limit of 1 Hz is the minimum flashing rate of traffic signals [15]. Accordingly, three different scenarios (D, E and F) were created to study the effect of the flashing rate of driver’s reaction time.

In the first scenario (Scenario A), the signs were displayed in a traditional manner as post-mounted on the road side, presented in Table 1 below. The aim of Scenario A is to display the current state of traffic signs that comply with MUTCD. The second scenario (Scenario B)
is intended to serve as the base case for determining the perception-reaction time of the drivers. In this scenario, the leading vehicle brakes without the presence of any sign physically or virtually. The third scenario (Scenario C) has 25 mph speed limit and pedestrian signs as AR-HUD flashing at 2Hz. The pedestrian sign is displayed at the same instance as the leading car brakes. Scenario C will be compared with Scenario B to determine whether the AR traffic sign delays the driver’s reaction.

Table 1: Post-mounted Signs in Scenario A

<table>
<thead>
<tr>
<th>Sign</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="SPEED LIMIT 25" /></td>
<td>R2-1: Regulatory sign indicating a speed limit of 25 mph.</td>
</tr>
<tr>
<td><img src="image" alt="W11-2" /></td>
<td>W11-2: Warning sign indicating there is a pedestrian crossing ahead.</td>
</tr>
<tr>
<td><img src="image" alt="W1-2" /></td>
<td>W1-2: Warning sign indicating a right curve ahead.</td>
</tr>
</tbody>
</table>

Traffic signs in Scenarios D, E and F were presented as AR-HUD shown in Table 2. The fourth scenario (Scenario D) has a right curve ahead and 55 mph speed limit signs flashing at 1Hz. At the end of the curve, the speed limit sign pops up and a second later the leading car brakes. The fifth scenario (Scenario E) has a 35 mph and 55 mph speed limit signs and the latter is displayed a second earlier than the braking of the leading car. The sixth scenario
(Scenario F) has a pedestrian crossing ahead and 35 mph speed limit signs. After couple of hundreds of feet after the pedestrian crossing, the speed limit is displayed and a second later the leading car brakes. Scenarios D, E and F are used to determine the effect of different flashing rate on driver’s reaction time. All scenarios with sign placements are illustrated in Table 3 below.

Table 2: Demonstration of AR-HUD Signs

<table>
<thead>
<tr>
<th>AR-HUD Traffic Signs</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td><img src="image.png" alt="Image" /></td>
<td>25 mph Speed Limit</td>
</tr>
<tr>
<td>AR-HUD Traffic Signs</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------</td>
</tr>
<tr>
<td><img src="image1.png" alt="35 mph Speed Limit" /></td>
<td>35 mph Speed Limit</td>
</tr>
<tr>
<td><img src="image2.png" alt="55 mph Speed Limit" /></td>
<td>55 mph Speed Limit</td>
</tr>
<tr>
<td>AR-HUD Traffic Signs</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>![Image](122x128 to 374x395)</td>
<td>Pedestrian Crossing Ahead</td>
</tr>
<tr>
<td>![Image](122x409 to 374x673)</td>
<td>Right Curve Ahead</td>
</tr>
</tbody>
</table>
Table 3: Illustration of the Scenario Layouts

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Layout and Placement of Signs</th>
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<tbody>
<tr>
<td>A</td>
<td><img src="image" alt="Diagram A" /></td>
</tr>
<tr>
<td>B</td>
<td><img src="image" alt="Diagram B" /></td>
</tr>
<tr>
<td>C</td>
<td><img src="image" alt="Diagram C" /></td>
</tr>
</tbody>
</table>
3.2 Design Considerations

In creating the scenarios, two types of environments were designed for this research; urban and suburban. Rural roadways were not included in the study because of their simplicity and low mental workload compared to urban and suburban [42]. To better serve the objective of the research, a more challenging environment was desired to have the subject fully attentive in the scenarios. Accordingly, the geometric characteristics of the roadways and lane configurations were used following the American Association of State Highway and Transportation Officials (AASHTO) Green Book. To set the design features in the simulation created, the design speeds were chosen to be 25, 35 mph and 55 mph for curve design and sign warning distance.

Setting the speeds to 25 and 35 mph on curves, the recommended side friction factors (f) by AASHTO are 0.23 and 0.18 respectively [1]. The relationship between speed and side friction is demonstrated below. The turning radii where determined by the table demonstrated below from AASHTO. AASHTO recommends superelevation (e) value of 2% for urban
The minimum horizontal curve radius for 25 mph design speed is 167 feet and for 35 mph is 408 feet.

Figure 3.1: Recommended Side Friction Factor (f) [1]

The minimum radii can be calculated according to the following formula:

\[
R_{\text{min}} = \frac{V^2}{15(0.01e_{\text{max}} + f_{\text{max}})}
\]  

[1]

Where,

- \( R_{\text{min}} \) = Minimum radius of curvature (ft)
- \( V \) = Design speed (mph)
- \( e_{\text{max}} \) = Max superelevation
- \( f_{\text{max}} \) = Maximum side friction
The placement of warning signs should provide an adequate distance for perception-reaction time (PRT); the time needed by the driver to detect, recognize, decide and initiate a response. Measuring PRT would start from the instant the sign becomes in the driver’s sight to the instant the driver initiates a response.

Based on the Manual of Uniform Traffic Control Devices (MUTCD), the upstream distance of post-mounted warning signs was selected. The guidelines for advanced placement of warning signs are presented in Table 4 below as presented in the MUTCD. For a speed limit of 25 mph, the advanced placement distance was determined to be 100 ft based on Condition B, since the speed of the vehicle decreases to a certain value.

Table 4: Advanced Placement of Warning Post-mounted Signs [15]

<table>
<thead>
<tr>
<th>Posted or 85th-Percentile Speed</th>
<th>Condition A: Speed reduction and lane changing in heavy traffic</th>
<th>Advance Placement Distance</th>
<th>Condition B: Deceleration to the listed advisory speed (mph) for the condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°</td>
<td>10°</td>
<td>20°</td>
</tr>
<tr>
<td>20 mph</td>
<td>225 ft</td>
<td>100 ft</td>
<td>N/A</td>
</tr>
<tr>
<td>25 mph</td>
<td>325 ft</td>
<td>100 ft</td>
<td>N/A</td>
</tr>
<tr>
<td>30 mph</td>
<td>469 ft</td>
<td>100 ft</td>
<td>N/A</td>
</tr>
<tr>
<td>35 mph</td>
<td>565 ft</td>
<td>100 ft</td>
<td>N/A</td>
</tr>
<tr>
<td>40 mph</td>
<td>670 ft</td>
<td>125 ft</td>
<td>100 ft</td>
</tr>
<tr>
<td>45 mph</td>
<td>775 ft</td>
<td>175 ft</td>
<td>125 ft</td>
</tr>
<tr>
<td>50 mph</td>
<td>885 ft</td>
<td>250 ft</td>
<td>200 ft</td>
</tr>
<tr>
<td>55 mph</td>
<td>990 ft</td>
<td>325 ft</td>
<td>275 ft</td>
</tr>
<tr>
<td>60 mph</td>
<td>1,100 ft</td>
<td>400 ft</td>
<td>350 ft</td>
</tr>
<tr>
<td>65 mph</td>
<td>1,200 ft</td>
<td>475 ft</td>
<td>450 ft</td>
</tr>
<tr>
<td>70 mph</td>
<td>1,250 ft</td>
<td>550 ft</td>
<td>525 ft</td>
</tr>
<tr>
<td>75 mph</td>
<td>1,350 ft</td>
<td>650 ft</td>
<td>625 ft</td>
</tr>
</tbody>
</table>

As mentioned in the AASHTO Green Book, the PRT can range between 1.5s and 2.5s based on the complexity of the situation and whether the driver is alerted or not. For all design considerations, PRT is defaulted as 2.5s.
For the design of AR-HUD pedestrian crossing sign, the stopping sight distance (SSD) was used to determine the upstream distance of displaying the sign. SSD comprises two distances; the distance the vehicle travels during PRT and the distance the vehicle needs to stop from the instant the brakes are applied.

\[ SSD = 1.47Vt + 1.075 \frac{V^2}{a} \]  \[1\]

Where,

- SSD = stopping sight distance, ft
- V = design speed, mph
- t = brake reaction time, 2.5 s
- a = deceleration rate, ft/s\(^2\)

The detailed stopping sight distances are presented in Table 5 obtained from AASHTO Green Book. As for the AR curve warning sign in Scenario D, the upstream distance from the point of curvature (PC) was based on the brake reaction distance only. For a speed limit of 35 mph, the sign was displayed as AR-HUD 130 ft upstream of PC.
Table 5: Stopping Sight Distance on Level Roadways [1]

<table>
<thead>
<tr>
<th>Design Speed (km/h)</th>
<th>Metric</th>
<th></th>
<th>U.S. Customary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brake Reaction Distance (m)</td>
<td>Braking Distance on Level (m)</td>
<td>Stopping Sight Distance Calculated (m)</td>
</tr>
<tr>
<td>20</td>
<td>13.9</td>
<td>4.6</td>
<td>18.5</td>
</tr>
<tr>
<td>30</td>
<td>20.9</td>
<td>10.3</td>
<td>31.2</td>
</tr>
<tr>
<td>40</td>
<td>27.8</td>
<td>18.4</td>
<td>46.2</td>
</tr>
<tr>
<td>50</td>
<td>34.8</td>
<td>28.7</td>
<td>63.5</td>
</tr>
<tr>
<td>60</td>
<td>41.7</td>
<td>41.3</td>
<td>83.0</td>
</tr>
<tr>
<td>70</td>
<td>48.7</td>
<td>56.2</td>
<td>104.9</td>
</tr>
<tr>
<td>80</td>
<td>55.6</td>
<td>73.4</td>
<td>129.0</td>
</tr>
<tr>
<td>90</td>
<td>62.6</td>
<td>92.9</td>
<td>155.5</td>
</tr>
<tr>
<td>100</td>
<td>69.5</td>
<td>114.7</td>
<td>184.2</td>
</tr>
<tr>
<td>110</td>
<td>76.5</td>
<td>138.8</td>
<td>215.3</td>
</tr>
<tr>
<td>120</td>
<td>83.4</td>
<td>165.2</td>
<td>248.6</td>
</tr>
<tr>
<td>130</td>
<td>90.4</td>
<td>193.8</td>
<td>284.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>75</td>
</tr>
</tbody>
</table>

3.3 Scenario Creation

Creating the scenarios for this research was of a very high importance. The scenarios were designed specifically to serve the objectives of the study. Although the scenarios are not site specific, the environments featured in them are typical urban and suburban environments. Scenarios were created on two stages; geometric design and animation.

The geometric features of the roadways were done first on AutoCAD 2015 creating a 2D drawing such as in Figure 3.2 in which was later imported into Blender. The horizontal alignments and cross sections of the roadways followed the AASHTO Green Book guidelines [1]. Based on the environments and purpose of the study, Roadways were designed as either
2-lane major urban collectors or 2-lane minor urban arterials. All scenarios were built on leveled terrains with at most one horizontal curve. As, the design speeds were set as 25, 35, and 55 mph across all scenarios, the design of curves followed.

![Figure 3.2: Layout of Scenario A](image)

Having the roadway geometric characteristics of the roadway designed, the 2D drawing was then imported into a 3D modeling software, Blender. In Blender, the 3D environment was created to make scenarios more realistic. Buildings, vehicles, pedestrians, trees, landscapes and other surface terrains were designed. The appropriate texture for each of the elements and features was then added shown in Figures 3.3 - 3.4.
Figure 3.3: Textures of Scenario C

Figure 3.4: Textures of Scenario F
After the design phase was completely done, the scenario was ready for animation. The vehicles were designed to follow the roadway at the designed speed. The tail lights in the leading vehicles were dynamic; illuminating once the vehicle slows down or stops. Since simulation videos were created, the camera was placed in the following vehicle at the location of the driver’s eye and was set to follow the roadway with the vehicle. Different pedestrian types were inserted; adults and kids; males and females to emulate a real environment. Then, they were modeled as shown in Figure 3.5 to animate their motion, setting their walking speed to 3.5 ft/sec, the walking speed used in MUTCD for designing purposes [15].

![Figure 3.5: Scenario F with Crossing Pedestrian](image)

Six different scenarios were created, each scenario is made up of 900 frames rendered at a rate of 30 frames/sec making them each 30 seconds in duration. All scenarios were designed from the driver’s perspective as presented in Figure 3.6.
The design of post-mounted signs, sign size and mounting height, followed the guidelines stated by the MUTCD, tables 2B-1 and 2C-2. The location of post-mounted signs installed in Scenario A is determined by the MUTCD standards as mentioned in Section 3.1, while that of the AR signs was based on providing sufficient PRT.

In the rest of the scenarios (B through F), all signs, if any, are displayed as AR images augmented on the real world as demonstrated. Due to the absence of solid guidelines for these types of signs, the design of the augmented reality traffic signs followed the design criteria set by Continental for AR-HUD. Accordingly the signs were displayed in an area of 130cm x 60cm, 7.5m away from the driver’s eye [6]. Noting that the restricted area of field of vision is still one of the limitations of augmented reality displays.
The AR-HUD traffic signs were flashing at either 1Hz, 2 Hz or 3Hz since dynamic displays draw the attention of drivers better than stationary displays [10], [37], [38]. While the sign is flashing, it doesn’t completely disappear but it goes brighter and dimmer. The transparency and brightness are set for 0.3 and 0.6 when the sign is in the bright phase and for 0.1 and 0.5 when the sign is the dim phase. The difference between the bright and dim phase is demonstrated in Figure 3.7. The signs keep flashing for a duration of 2.5 sec, a sufficient duration of time for more than 90% of the drivers to perceive and initiate a response [1].

![Figure 3.7: Example of the Bright and Dim Phases of the Flashing Sign](image-url)
3.4 Testing Procedure

Eighty-eight subjects participated in this study to run the analysis, out of which two dropped out for unknown reasons. Due to the absence of predictors and estimators, the sample size needed couldn’t be estimated. However, to assume normality by Central Limit Theorem (CLT), the sample size should be a minimum of 30 [43]. In addition, as the sample size increases, the power and accuracy of the statistical analysis increases. The subjects consisted of sixty-three males, twenty-four females and someone who didn’t wish to answer. The age of participants ranged between 19 and 65 years old with an average age of 28 years old and standard deviation of 11 years. Whereas their driving experience ranged between 2 and 50 years with an average of 10 years and standard deviation of 12 years.

The design of the experiment as well as the testing procedure comply with Institutional Review Board (IRB) guidelines. Before the testing could begin, the participants were briefed about the research and its objectives. Then, subjects were given detailed instructions about the tasks they are assigned.

The subjects were asked to watch a set of 6 short videos, 30 seconds each. The videos were played on a 1920 x 1200 Pixel Resolution, 24” LCD screen, at about 26 inches away from the subject. At the beginning of the session, they were informed that the videos are viewed from the driver’s perspective. They were asked to attend to the road as if they were driving themselves. They were told that they will be following a leading vehicle. They were introduced to the controls they had to use; a brake pedal, right controller and left controller presented in Figure 3.8.
Their main task was to press the brake pedal when the leading car brakes. Noting that the car would brake unexpectedly. The subjects were assigned a secondary task to keep them engaged while watching the video to emulate a real driving situation. The secondary task was a roadside visual detection task which is defined to pressing a button on the right controller once they spotted a blue box shown in Figure 3.9 on the right side of the road and pressing a button on the left controller once they spotted a blue box on the left side of the road. This task helps in identifying whether the presentation of traffic signs as AR-HUD would result in a lower recognition of objects on the sides of the roads.
Once the instructions became clear to them, they were given testing templates to become familiar with the nature of the test and to get accustomed to the controls. When they felt comfortable with the instructions and controls after the test trials and all their questions were addressed, they proceeded with the experiment. To eliminate biased responses through learning effects, the videos were randomly ordered for each subject. After the end of each video, the subjects could have a break if they needed to.

3.5 Data Description

Driver’s reaction time was recorded for each subject in every scenario. Once the subject presses the pedal, right controller and left controller, the time instant would be saved with the identification of the pressed controller. Eleven data points were extracted for each subject.
across all scenarios and presented in Tables 15 and 16, found in Appendix B. Each scenario had two data points except for Scenario A. The primary one is for pressing the brakes when the leading car brakes. Another secondary point is when a box was appearing within the time frame of sign displaying. The data point was extracted when participants pressed the button for that specific box. The reaction time was measured based on the difference in time (in milliseconds) from the instant the leading car brakes (Table 6) till the instant the driver presses the pedal for one and from the instant the box appears (Table 7) till the participant pressed the button. The six scenarios of the experiment were the same for all participants but presented randomly. The time frames where the car braked, the signs were displayed and boxed appeared were different among scenarios but constant amongst participants.

Table 6: Time Frames of Braking Leading Car

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>FRAME AT BRAKING</th>
<th>TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>255</td>
<td>8.5</td>
</tr>
<tr>
<td>B</td>
<td>604</td>
<td>20.13</td>
</tr>
<tr>
<td>C</td>
<td>600</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>520</td>
<td>17.33</td>
</tr>
<tr>
<td>E</td>
<td>520</td>
<td>17.33</td>
</tr>
<tr>
<td>F</td>
<td>520</td>
<td>17.33</td>
</tr>
</tbody>
</table>

Table 7: Time Frames of Box Appearance

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>FRAME AT BOX APPEARANCE</th>
<th>TIME (SEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35</td>
<td>1.17</td>
</tr>
<tr>
<td>B</td>
<td>160</td>
<td>5.33</td>
</tr>
<tr>
<td>C</td>
<td>152</td>
<td>5.07</td>
</tr>
<tr>
<td>D</td>
<td>250</td>
<td>8.33</td>
</tr>
<tr>
<td>E</td>
<td>200</td>
<td>6.667</td>
</tr>
<tr>
<td>F</td>
<td>135</td>
<td>4.5</td>
</tr>
</tbody>
</table>
3.6 Statistical Analysis

Before starting the analysis, the collected data was tested for normality to determine the appropriate test to apply. With some missing data points and some point lying far outside the expected range, the raw data was skewed and had to be filtered. Due to the variety of the sample size and the wide range of the data points, it could not be assumed that the sample was normally distributed. Thus, the Median Absolute Deviation (MAD) was used to detect outliers from the data set. The median, as the mean, is a measure of central tendency; however, it is more robust and insensitive to the presence of outliers [44], [45].

\[
MAD = \text{median}_i \{|x_i - \bar{x}|\}
\]

\[
M_i = \frac{0.6745(x_i - \bar{x})}{MAD}
\]

Where,

MAD = median absolute deviation

\(x_i\) = an observation of the original sample for \(i = 1, 2 \ldots n\)

\(\bar{x}\) = sample median

\(M_i\) = MAD score

Any observation that has an absolute value of \(M_i\) that’s greater than a maximum permissible MAD score of 3.5 is labelled as an outlier and is omitted from the data set [47]. Doing so, the number of data points was reduced to 57. By using CLT, the sample is considered to be normally distributed as long as the sample size is greater than 30 [43]. Accordingly, a paired comparison t-test was used to determine whether the reaction times would differ significantly across the scenarios. A t-test was convenient for the sample size studied; however, it is important to note the limitations of a t-test. As the sample size increases, the results of a t-
test might differ due to the emergence of different trends. An insignificant t-test on a small sample size might turn out to be significant on a bigger sample size. The t-test has so much power with a big sample size, as the slightest difference becomes significant.

For the analysis, the statistical program, RStudio, was used to perform this test. P-values, also known as probability value were computed for different scenario comparisons. P-value determines the probability that the test-statistic is equal to the observed value under the assumption that the null hypothesis is true. The p-value is compared with a threshold $\alpha$ that is set to 0.05. Accordingly, if $p$-value $< 0.05$, then the null hypothesis is rejected and the alternative one is supported.

Three hypothesis tests were addressed to serve the objectives of this research. As the first objective is determining whether the AR traffic signs can delay the driver’s reaction to other competing cues, Scenarios B and C are compared and the first hypothesis test ($H_1$) is set as:

$H_{1,0}$ – null hypothesis: $RT_B \leq RT_C$

The reaction time to braking in the presence of a flashing sign is greater than or equal to the reaction time in the absence of traffic sign.

$H_{1,A}$ – alternative hypothesis: $RT_B > RT_C$

The reaction time to braking in the presence of a flashing sign is less than the reaction time in the absence of the sign.
The second hypothesis test ($H_2$) is set to determine the effect of sign flashing rates on the reaction time by comparing data point across Scenarios D, E and F. Scenario D has flashing signs at a rate of 1 Hz, Scenario E at 2 Hz and Scenario F at 3 Hz.

$H_{2,0}$ – null hypothesis: $RT_{1Hz} = RT_{2Hz} = RT_{3Hz}$

The reaction times for flashing rate of 1 Hz, 2 Hz and 3Hz are equivalent.

$H_{2,A}$ – alternative hypothesis: $RT_{1Hz} \neq RT_{2Hz} \neq RT_{3Hz}$

The reaction times for at least two flashing rates are not equivalent.

the reaction time in the absence of the sign.

The third hypothesis ($H_3$) tests whether the reaction times in a scenario with AR-HUD signs is equivalent to that in a scenario with post-mounted signs. A comparison of reaction times is held between scenarios A and C.

$H_{3,0}$ – null hypothesis: $RT_A = RT_C$

The reaction times in the presence of AR-HUD is equivalent to that in the presence of post-mounted signs.

$H_{3,A}$ – alternative hypothesis: $RT_A \neq RT_C$

The reaction times in the presence of AR-HUD is not equivalent to that in the presence of post-mounted signs.
4. ANALYSIS AND RESULTS

4.1 Data Analysis

The reaction times of all participants in all scenarios is demonstrated in the box plot below (Figure 4.1). This plot is the presentation of the raw data, before filtering the outliers. The average of all reaction times range between 0.5 sec and 1 sec. Some participants had a higher reaction time reaching 5 sec. This was due to the concentration on the secondary task and forgetting about the primary task as they explained. In scenarios D, E and F, there were couple of instances when subjects would press the brakes when they see the sign instead of when the leading vehicle brakes, thus the negative and small reaction times. The order of the scenarios might be another reason for such outliers. Although the order of the scenarios was totally randomized for the subjects, the subject might perform poorly in the first scenario the subject encounters. In addition, sometimes subjects would press the pedal but not hard enough to activate it and record the data. These data points were lost as well. Those very high and very low data points were labelled as outliers according to MAD and they were excluded from the analysis resulting in a filtered sample size of 58. As a result, the filtered data was left and could be examined thoroughly. Figure 4.2 presents the box plot of the filtered perception-reaction times. The probability density functions for each scenario can be seen in Figures (7.1 - 7.6) of Appendix A.
Figure 4.1: Perception-Reaction Times (sec) of Raw Data
Examining the box plot from a wide and general point of view, it can be seen that the averages of reaction times across the six different scenarios were different, some more significant than others. The fastest average reaction time was in scenario F (flashing rate at 3 Hz), whereas the slowest average reaction time was in scenario B (absence of sign). In each of the scenarios, the reaction times had a different range and deviation from the mean.

Noting that the average of all scenarios ranges from 0.5 to 1 sec. To validate the experiment, the results obtained were correlated with several previous studies of reaction
times. A study found out that the average of reaction time of drivers was 0.64 sec [48], while another study had values of reaction time range between 0.4 to 1.7 sec [49]. Johansson and Rumar found that the median of reaction time for drivers who expected to press the brakes was 0.66 sec [50]. With compiling all these studies and ranges of average reaction time, the results obtained from this research could be easily fit in those ranges.

Starting with the first hypothesis test, Scenarios B and C are compared to check whether the presence of a flashing traffic sign delays the driver’s reaction to another competing cue. The results are presented in Table 8.

Table 8: P-value of Hypothesis 1

<table>
<thead>
<tr>
<th>SCENARIOS</th>
<th>Degrees of Freedom</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B VS C</td>
<td>57</td>
<td>2.274e-07</td>
</tr>
</tbody>
</table>

Since P-value is less than 0.05, then the null hypothesis is rejected in favor of the alternative hypothesis. Thus, the reaction time to the external cue (leading braking vehicle) is not delayed by the presence of a flashing traffic sign. But on the contrary, the reaction times were faster. Although the flashing signs were not warning the driver about the sudden braking of the leading vehicle; however, it would be safe to say that the presence of the sign in the driver’s line of sight would direct his attention back to the road in case of other distractions. As for Hypothesis 2, the results are displayed in Table 9.
Table 9: P-values of Hypothesis 2

\[ H_{2,0} – \text{NULL HYPOTHESIS: } RT_{1HZ} = RT_{2HZ} = RT_{3HZ} \]
\[ H_{2,A} – \text{ALTERNATIVE HYPOTHESIS: } RT_{1HZ} \neq RT_{2HZ} \neq RT_{3HZ} \]

<table>
<thead>
<tr>
<th>SCENARIOS</th>
<th>Degrees of Freedom</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>D VS E</td>
<td>57</td>
<td>3.007e-07</td>
</tr>
<tr>
<td>D VS F</td>
<td>57</td>
<td>2.606e-06</td>
</tr>
<tr>
<td>E VS F</td>
<td>57</td>
<td>1.367e-12</td>
</tr>
</tbody>
</table>

Since all p-values are less than 0.05, the null hypothesis is rejected and the alternative one is supported. Thus, the flashing rate has a significant effect on the driver’s reaction time. In coordination with the box plot, it can be inferred that a flashing rate of 3 Hz has the fastest reaction time. This result was expected, since a fast flashing rate would attract driver’s attention faster than a relatively slower one. While the flashing rate of 2 Hz has the slowest reaction time, even slower that at a rate of 1 Hz. This might be due to the familiarity of drivers with the flashing rate of 1 Hz; the rate used in all flashing traffic signal which makes them react faster to it that to a rate of 2 Hz. The results of Hypothesis 3 are tabulated below in Table 10.

Table 10: P-values of Hypothesis 3

\[ H_{3,0} – \text{NULL HYPOTHESIS: } RT_A = RT_C \]
\[ H_{3,A} – \text{ALTERNATIVE HYPOTHESIS: } RT_A \neq RT_C \]

<table>
<thead>
<tr>
<th>SCENARIOS</th>
<th>Degrees of Freedom</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A VS C</td>
<td>57</td>
<td>0.1126</td>
</tr>
</tbody>
</table>
For the third hypothesis, the p-value is greater than 0.05, then the null hypothesis is true. As a result, the driver’s reaction time in a scenario with AR-HUD traffic signs is equivalent to the reaction time in a scenario with post-mounted signs.

In this study, there were other dependent variable such as gender, age, and driving experience. Based on previous researches, those factors might have an effect on the results of the experiment. But due to the unbalanced sample size for the levels of these factors demonstrated in Table 11, the mentioned variables couldn’t be integrated in the analysis as factors. However, the average reaction times were compared for each factor at its two different levels. The average reaction times for males and females across all scenarios are presented in Figure 4.3.

Table 11: Sample size of Data Set

<table>
<thead>
<tr>
<th>SAMPLE SIZE</th>
<th>Raw Data</th>
<th>Filtered Data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GENDER</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>61</td>
<td>43</td>
</tr>
<tr>
<td>Female</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>Didn’t wish to answer</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>AGE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young (19-35 years old)</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>Middle/Old (36-65 years old)</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td><strong>DRIVING EXPERIENCE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In experienced (≤ 4 years)</td>
<td>35</td>
<td>21</td>
</tr>
<tr>
<td>Experienced (&gt; 4 years)</td>
<td>53</td>
<td>37</td>
</tr>
</tbody>
</table>
**Figure 4.3:** Perception-Reaction Times for Males and Females

**Table 12:** P-values for Males vs Females

<table>
<thead>
<tr>
<th>SCENARIOS</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MALE VS FEMALE</strong></td>
<td>0.2431</td>
<td>0.4734</td>
<td>0.457</td>
<td>0.5326</td>
<td>0.118</td>
<td>0.3352</td>
</tr>
</tbody>
</table>

**NULL HYPOTHESIS:** $RT_M = RT_F$

**ALTERNATIVE HYPOTHESIS:** $RT_M \neq RT_F$
In all scenarios, females had slightly greater, but insignificant, reaction times than that of males. P-values are shown in Table 12. These results are somewhat biased, noting that the sample size of females (24) is much smaller than that of the males (63). As for age as the second factor, the participants were divided into two categories: young and middle/old. Any participant who was between 19 and 35 years old were classified as young. While middle and old people ranging from 36 years old to 65 years old were grouped in one category due to their small sample size. The average reaction times for young and middle/old subjects can be seen in Figure 4.4.
Figure 4.4: Perception-Reaction Times for Young and Middle/Old Drivers
Table 13: P-values for Young Drivers vs Middle/Old Drivers

**NULL HYPOTHESIS:** $RT_Y = RT_{M/O}$
**ALTERNATIVE HYPOTHESIS:** $RT_Y \neq RT_{M/O}$

<table>
<thead>
<tr>
<th>SCENARIOS</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>YOUNG VS</td>
<td>0.0722</td>
<td>0.01476</td>
<td>0.1836</td>
<td>0.0610</td>
<td>0.1483</td>
<td>0.1574</td>
</tr>
<tr>
<td>MIDDLE/OLD</td>
<td></td>
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There was a clear difference between the averages of these two categories over all scenarios. However, this difference was only significant in scenario B, as shown in Table 13 where the car applies the brakes in the absence of a sign. This might be due to the younger generation being more alert.

Driving experience was the third factor considered since perception-reaction times might change with driving experience. Subjects were divided into two categories based on their driving experience. If they have a driving experience of four years or less, they were classified as inexperienced [51]. The results are presented in Figure 4.6. This factor was significant in Scenario A in the presence of post-mounted signs shown in Table 14. Where as in the scenarios with AR-HUD traffic signs there wasn’t any significant difference. This might be due to the new introduction of this type of sign to both categories.
Figure 4.5: Reaction Times for Experienced and Inexperienced Drivers
Table 14: P-values for Experienced Drivers vs Inexperienced Drivers

**NULL HYPOTHESIS:** RT_E = RT_I  
**ALTERNATIVE HYPOTHESIS:** RT_E ≠ RT_I

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<th>SCENARIOS</th>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
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As for the secondary task, blue boxes were appearing on both signs of the roads and the subjects were expected to detect them. In particular, in every scenario there was a box that pops out in the time frame of AR-HUD traffic sign displaying. It was desired to know if the presentation of the traffic sign in the driver’s line of sight would decrease the level of recognition of objects on the road side. The % of boxes detection is demonstrated in Table 15. All scenarios had a high % of detection except for Scenario F. This might be due the effect of the pedestrian crossing sign that makes driver’s focus on the pedestrian instead of scanning the roadsides. In order not to lower driver’s recognition of the surrounding area, a lower flashing rate could be used for the pedestrian crossing ahead sign.

Table 15: Percentage of Boxes Detection

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<th>C</th>
<th>D</th>
<th>E</th>
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<td>90.70</td>
<td>96.51</td>
<td>90.70</td>
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</table>
4.2 Findings

Following the analysis that was discussed in the previous section, the comparison that was conducted between scenarios B and C, indicated that the driver’s reaction to a competing cue was not delayed when the signs were presented as flashing holograms. On the contrary, the drivers’ reaction times were faster. It is reasonable to say that the display of traffic signs in the form of holograms doesn’t delay driver’s reactions to other concurrent significant cues, but holograms augment the driving task by directing the driver’s attention back to the road.

From the second hypothesis test, it is inferred that the flashing rate of the AR traffic signs has a significant effect on the driver’s reaction time. The flashing rate of 3 Hz had the fastest reactions making it very efficient for urgent warnings. Whereas a flashing rate of 1 Hz would be better in presenting regulatory and guidance signs.

The third hypothesis resulted in equivalent reaction times when signs are presented in the form of AR displays compared to post-mounted signs. This strengthens the theory of having AR traffic signs being a potential replacement for the post-mounted ones.

It is important to note that other than the dependent variables that were tested in this study, there were other factors that might have an impact on the results. Driver’s performance could be affected by age and driving experience for the sample size studied in this research.
5. CONCLUSION

As driver’s error contributes to 75 – 95% of the crashes [2]–[5], the in-vehicle systems can be helpful to the driver by presenting real-time information that is needed at the right place. Avoiding mistakes and violations in driving could help in reducing the crash rates. Since TCDs is the primary form of communication with drivers, integrating TCD in the automobile system would be a great step towards safer and more efficient roadway systems.

With the fast pace of automobile technological advancements, it is necessary to test any potential system that’s about to be integrated in automobiles. As the previous research has shown that virtual traffic control devices has the same impact on driver’s performance compared to the traditional post-mounted ones based on speed profiles [14]. It is important to examine the effects of those types of displays on driver’s performance and distraction based on perception-reaction times.

This experiment, with a sample size of eighty-eight participants, examined the driver’s reaction time to competing cues when traffic signs are presented in the form of AR displays. The participants were asked to watch 6 different scenarios and they were expected to press the pedal when the leading car brakes. Noting that the leading brakes suddenly at the same time or a little after a AR traffic sign flashes. The results indicated limited potential to none, for distraction to be associated with the display of AR traffic signs. Also, the flashing rate that causes the fastest reaction is of 3 Hz. Noting that fastest doesn’t always mean the best; in some cases, a fast reaction time might lead to harsh consequences. Therefore, a flash rate of 3 Hz could be recommended for warning signs that require urgent response. Highlighting the fact that driving performance in an AR-HUD environment augments the driving task better than
that of a traditionally signed environment, along with showing that AR signs do not delay driver’s reaction time to other competing cues, it is reasonable to say that AR Traffic Control Devices can communicate with drivers more effectively than the traditional ones. Accordingly, AR-HUD TCDs could be a potential replacement for the traditional ones in a technological advanced world.

5.1 Future Research

With all these technological advancements in the automobile industry, there is a great potential for the employment of AR-HUD. Expecting a world with connected and autonomous vehicles provides a window to keep exploring and researching the different applications of AR-HUD to augment the driving task. With that, the safety and efficiency of the transportation facilities would be greatly improved. To increase the sensitivity of the results obtained in the research, more data could be added to the sample size studied. This allows the convergence of the results to a clear specific trend. In addition, the sensitivity could be enhanced by balancing the sample size based on the demographic factors and taking into account other dependent variables.

To follow up with the results obtained from this study, a second phase should be performed on a full driving simulator to emulate an even more realistic environment and for higher fidelity results. By using the driving simulator, new measures of effectiveness could be introduced to better study the driver’s performance as well as the distraction factors. Some of those measures are lane deviation, time to collision, and speed profiles.
It would be interesting to test those signs in different situations such as familiar versus unfamiliar areas with varying the workload and environment. Also, a wide range of signs could be tested in similar scenarios; work zone signage can be introduced.
6. REFERENCES


[27] K. M. Bach, M. G. Ja eger, M. B. Skov, and N. G. Thomassen, “Interacting with in-vehicle systems: understanding, measuring, and evaluating attention,” in Proceedings of


7. APPENDIX

7.1 Appendix A

Figure 7.1: Pdf of Scenario A

Figure 7.2: Pdf of Scenario B
Figure 7.3: Pdf of Scenario C

Figure 7.4: Pdf of Scenario D
Figure 7.5: Pdf of Scenario E

Figure 7.6: Pdf of Scenario F
### 7.2 Appendix B

**Table 16: Raw Data for Driver Reaction Time to Braking**

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Figure 7.7: Reaction Times in Scenarios B and C
Figure 7.8: Reaction Times in Scenarios D (1Hz), E (2Hz) and F (3Hz)
### Table 17: Time Instances of Box Detection

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