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Radhameris A. Gomez Gabriel

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**AN EVALUATION OF TRAFFIC CONTROL DEVICES AND DRIVER DISTRACTION
ON DRIVER BEHAVIOR AT RAILWAY-HIGHWAY GRADE CROSSINGS**

A Dissertation Presented

by

RADHAMERIS A. GÓMEZ GABRIEL

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

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May 2017

Civil and Environmental Engineering

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BEHAVIOR AT RAILWAY-HIGHWAY GRADE CROSSINGS**

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DEDICATION

A mis padres, Juan Radhamés Gómez & Felicia Altagracia Gabriel, por su amor, apoyo incondicional, y todos sus sacrificios. A mi hermano Juan Raimy Gómez, por enseñarme que el vínculo familiar es eterno.

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ABSTRACT

AN EVALUATION OF TRAFFIC CONTROL DEVICES AND DRIVER DISTRACTION ON DRIVER BEHAVIOR AT RAILWAY-HIGHWAY GRADE CROSSINGS

MAY 2017

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At-grade crossings (grade crossings) are those crossings in which any part of a roadway intersects with railroad tracks. Safety at these railroad-highway grade crossings is a major concern, with traffic control warning devices serving as the main mechanisms for improving safety.

There are three factors that influence a driver's behavior at a given crossing. First, traffic control devices, including warning devices at the railroad-highway grade crossings, provide the driver with information whose impact will depend in part on the likelihood that the driver knows whether to glance in the direction of the device based on prior experience, and in part on what the driver understands the warning device to mean. Second, assuming that the driver identifies the warning, the driver's prior knowledge influences his or her expectancy regarding various railroad-highway grade crossing situations and, therefore, the way in which the driver responds to the hazard presented by the crossing. Finally, the driver's own

physiological (e.g., impaired) and psychological (e.g., distracted) state will modify the role that conspicuity and expectancy have on the driver's behavior.

For any given level of, expectancy and driver state, crashes can and do occur at crossings. These crashes typically occur because: 1) a driver never sees the railroad-highway grade crossing, 2) a driver does not select an appropriate speed and/or path through the crossing or 3) a driver does not successfully execute an appropriate decision. Distraction can be an element in all three types of causes of crashes. This dissertation centers on the impact of distraction and the effect of traffic control and warning devices have on stopping behavior and glance behaviors at non-gated railroad-highway grade crossings and studies a possible countermeasure which when combined with traffic control and warning devices can mitigate the effects of distraction due to less than optimal glance patterns.

In order to address the gap that exists in our understanding of driver distraction at railroad-highway grade crossings, two driving simulator experiments were conducted that arguably targeted the most critical need, in particular the need to identify the role that distraction has on the effectiveness of traffic control and warning devices at grade crossings. Ninety-nine participants were evaluated across the two driving simulator experiments. For the first experiment, the role distraction plays in reducing the benefit of crossbuck and flashing lights was analyzed. Participants either engaged in a distracting task or did not engage. The secondary tasks included a mock cell phone conversation or an in-vehicle task where the participant driver was asked to change the radio station. Eye movement and stopping behavior

was collected for all participants in both studies. The first experiment showed participants in all groups had trouble navigating the grade crossing environment thus pointing to the need to evaluate supplementary treatments which may benefit driver behavior at these crossings. The second simulator experiment evaluated the impact of the dynamic envelope pavement markings on driver glance pattern and behavior as they approached grade crossings while drivers also performed a distracting or non-distracting task. The dynamic envelope is painted on the region between and immediately adjacent to the tracks. Results show that the addition of these markings can alert drivers of the presence of a grade crossing with anticipation, and as a result induce drivers to glance more and potentially stop in higher proportions than when the markings are not present.

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CHAPTER 1

THE AT-GRADE CROSSING PROBLEM

1.1 Introduction

U.S. Federal statistics show a downward trend in the number of incidents at railway-highway at-grade crossings (herein referred to as grade crossings), yet the number of fatalities at these crossings remains appalling. A total of 2,075 railroad-highway grade crossing vehicle-train collisions occurred in 2015, resulting in 244 deaths and more than 1000 injuries (FRA Database, 2015 Statistics). The U.S. Federal Railroad Administration (FRA) statistics show that close to 94 percent of these train-vehicle collisions can be attributed to driver behavior and poor judgement, and thus preventable (FRA RR 16-10, 2016). The National Highway Traffic Safety Administration (NHTSA) reports that a motorist is almost 20 times more likely to die in a crash involving a train than in a collision involving another motor vehicle (NHTSA, 2012).

Although driver inattention has been widely cited as a contributing factor in train-vehicle collisions (Horton et al., 2006) ;(OLI, 2009), historical policy-making has almost always placed the motorists as the villain frontrunner. In 1877, the United States Supreme Court Case of Continental Improvement Company v. Stead, 95 U.S. 161, 5 Otto 161, 24 L.Ed. 403 (1877) addressed the responsibilities of motorist and the railroad industry as “mutual and reciprocal” (Pottroff, 1998), except trains are heavy – thousands of tons heavy and thus have a hard time coming to a complete stop, which as a result almost always gives the train the right of way.

It wasn't until 1973 when the debate over who had the responsibility to stop led to the creation of the Federal-Aid Rail Highway Crossing Program (present day Railway-Highway Crossings -Section 130) Program as part of the Federal Highway Act of 1973. Section 130 was the result of political debate spearheaded by the Interstate Commerce Commission (ICC) in which the ICC argued that *"the solution to the grade crossing problem was to transfer the financial burden and planning of crossing improvements to the highway authority."* According to the ICC *"highway users are the principal recipients of the benefits"* (Mok & Savage, 2005). Section 130 apportions funds to the States by formula; these funds are provided for the elimination of hazards at railway-highway crossings at a 90% federal share – the remaining 10% comes from the railroads, the state highway authority, the municipality or a combination of the three.

Fifty percent of a State's apportionment under 23 USC 130(e) is dedicated for the installation of protective devices at crossings, yet according to the FRA, only half of the 127,862 public grade crossings have automatic-warning systems and only one-third have gates and flashing lights (FRA,2015) – meaning that the vast majority of public grade crossings are just one step above meeting the Federal standard which requires the placement of one crossbuck in each direction of travel, at a minimum (MUTCD, 2009). Most importantly, just because these crossings meet the minimum standards does not imply these standards are adequate.

In addition to understanding the policies that created the dynamic we see today in grade crossing safety, it is important to understand the underlying decision-making that provided the basis for the creation and use of the Traffic Control Devices (TCD's) which are present today at grade crossings.

The precursor of the present-day flashing lights was installed in 1930, by the Central Railroad of New Jersey in Sewaren, New Jersey (Fisher, 1951). By 1930, with over 60 different warning devices being used by different railroads, the American Association of Railroads (AAR) decided that the two *“most widely favored devices”* become the national standard; the two alternately-flashing horizontal lights we see today being one of the favorites (Fambro et al., 1990). In the 1978 edition of the Manual on Uniform Traffic Control Devices (MUTCD) highway-rail grade crossing TCD needs were officially addressed by including a new section which provided engineers with guidance on addressing grade crossing safety. Since then, the MUTCD has dictated the size, application, placement, and need for TCD’s at grade crossings.

Since 1877, society has evolved by leaps and bounds. Thanks in part to the policy changes made in the last century, our grade crossings are better equipped with automated flashing lights, signal preemption, and sometimes gates. We also enjoy a gamut of electronic devices (most prominently the cell phone), and let’s not forget driverless vehicles; yet more than ever, U.S. road users are faced with the same challenge of generations past - the challenge of properly detecting and safely negotiating a grade crossing, every time.

With the average U.S. household owning five electronic devices connected to the internet via Wi-Fi, wired or cellular networks (0), it would be no surprise that this increase in electronic gadgets migrates into the vehicular environment, causing drivers to disengage from the driving task. In fact, previous research by Klauer et al. (2006) concluded that drivers engaging in secondary visually or manually complex tasks had three times higher near

crash/crash risk than drivers who were attentive (i.e., not engaged in a secondary task). The combination of distraction and grade crossings is almost always deadly. Given these facts, it becomes imperative that the issue is addressed.

1.2 Research Motivation & Objectives

Although much is known about driver distraction behind the wheel (Horrey & Wickens, 2006) (Samuel et al., 2011) (Taylor et al., 2013) and the fact that inattentive drivers contribute to approximately 3 percent of all vehicle-train crashes at grade crossings (Horton et al., 2006), very little is known as to the impact of distraction on the driver's ability to look at the warning devices and act appropriately to avoid a crash, particularly when the driver is distracted.

After an initial consideration of the research to date, the regulations governing grade crossing safety, and the prevalent concern for safety at grade crossings, the followings objectives were developed to accomplish the goal of this dissertation:

1. Address the role that distraction has on the effectiveness of warning devices (crossbuck with flashing lights) when the driver is performing a distracting task;
and
2. Based on the evaluation of the warning configuration, determine a potential improvement to the current warning devices configuration which can provide a greater level of awareness to the road user of the potential presence of a train.

By combining traffic engineering standards and human factors concepts, two simulator evaluations were performed in order to quantify driver's glance and compliance behavior as they navigated a virtual environment of twelve non-gated, active grade crossings.

1.3 Experiments

A driving simulator allows for the evaluation of traffic situations which would be too dangerous in the open road. An RTI, Inc. Driving Simulator located at the Arbella Insurance Human Performance Lab at the University of Massachusetts Amherst was used to conduct this research. The first experiment evaluated: 1) the current state of the majority of crossings in the U.S. – that is, non-gated, and equipped with the crossbuck and flashing lights and 2) quantified the possible fatal implications that accompany a driver performing a distracting task while driving towards and in the vicinity of a grade crossing. The second experiment introduced a supplemental treatment to the configuration evaluated in experiment 1 and evaluated its impact in potentially improving driver behavior at these crossings.

1.3.1 Experiment 1

During the first simulator experiment, participants navigated a virtual world operating the controls of a driving simulator located in the Arbella Insurance Human Performance Lab at the University of Massachusetts Amherst. Participants encountered grade crossings as they navigated through the virtual environment. In experiment 1, participants completed two (2) simulated drives with six (6) scenarios in each drive. Each drive contained scenarios of interest “trick scenarios” in which participant's stopping and eye movement behavior were scored and

analyzed. All scenarios were driven by all participants and the secondary task performed was randomly assigned between participants. Research participants were assigned to one of three groups: control, distracted (in-vehicle task), or distracted (mock cell phone conversation).

1.3.2 Experiment 2

The second experiment also made use of the RTI, Inc. driving simulator. An alternative treatment was added to the standard TCD configuration evaluated in Experiment 1. The treatment selected for evaluation was the Dynamic Envelope Pavement Markings. The pavement markings were chosen for evaluation because their proper use can potentially provide a cost effective alternative to enhancing grade crossing visibility (Gabree et al., 2014).

CHAPTER 2

LITERATURE REVIEW

2.1 Background

Safety on our nation's railroads continues to be a prevailing concern, particularly as it relates to safety at railway-highway grade crossings. Railway-highway grade crossings (referred to as grade crossings throughout this document) are those intersections in which any part of a roadway intersects with railroad tracks at the same level or grade. The traffic control device (TCD) found at the crossing dictates its classification; if the crossing configuration includes flashing lights and other dynamic components, the crossing is considered to be "*active*". On the other hand, if the crossing is only controlled by a cross buck and an advance warning sign, then the crossing is considered to be "*passive*." In the U.S., a disproportionate number of train-vehicle crashes happen at active crossings (0).

2.1.1 Traffic Control Devices & the Law

The main role of a Traffic Control Device (TCD) is to provide the driver with information so that he/she can move throughout the transportation network safely. The Manual on Uniform Traffic Control Devices (MUTCD, 2009) states that a good traffic control device must:

- Fulfill a need,
- command attention,
- command respect,

- convey a simple and clear message, and
- provide ample time for proper response.

At at-grade crossings, the most frequently used TCD's are warning devices, typically a crossbuck sign and flashers. Warning devices serve as a way of alerting the driver of possible danger ahead (advance warning sign) and of the actual presence of the threat at the crossing (flashers). Drivers encounter a number of warning devices as they approach a grade crossing, mainly pavement markings and signage, and as they pass the crossing primarily flashing lights, frequently combined with an automatic gate.

At at-grade crossings, trains have the right of way because it is much harder for a train to come to a complete stop and avoid a collision in comparison to a motorist. Therefore, the responsibility of completing a safe crossing belongs to the road user. Regulations and standards for safety at grade crossings involve a number of stakeholders. The American Association of State Highway and Transportation Officials (AASHTO) provide guidance through the publication of "A Policy on Geometric Design of Highways and Streets", also known as the Green Book. AASHTO also provides other recommendations regarding the overall geometry of the crossing. The Federal Highway Administration (FHWA) provides additional guidance through the Manual on Uniform Traffic Control Devices; known as the "bible" of traffic engineering. The MUTCD sets minimum national standards for the use of TCD's. The FHWA also publishes the Railroad-Highway Grade Crossing Handbook, which offers general guidance for making physical and operational improvements to grade crossings (0 2002). The American Railway Engineering and

Maintenance-of-Way Association (AREMA) publishes the Communications and Signal Manual which sets standards for the electrical and circuit systems which operate the rail right-of way and provide input for the proper function of gates at the grade crossings.

Every State is responsible for developing and enforcing needs-based traffic codes and rules which serve as a supplement to the minimum standards required by the MUTCD. The correct driver behavior when meeting a traffic device is dictated by the Uniform Vehicle Code (UVC) which is prepared by the National Committee on Uniform Traffic Laws and Ordinances, a non-profit organization, made up of state governments in addition to other related organizations (**Error! Reference source not found.**, 2013). As with the MUTCD, each state is then responsible for enforcing the law according to their standards.

2.1.1.1 Manual on Uniform Traffic Control Devices (MUTCD Standards)

According to the Manual on Uniform Control Devices (MUTCD):

At a minimum, one crossbuck (**Figure 1**) sign shall be used on each highway approach to every railroad-highway grade crossing, alone or in combination with other traffic control devices. If automatic gates are not present and if there are two or more tracks at a grade crossing, the number of tracks shall be indicated on a supplemental Number of Tracks (R15-2P) plaque of inverted T shape mounted below the crossbuck sign.

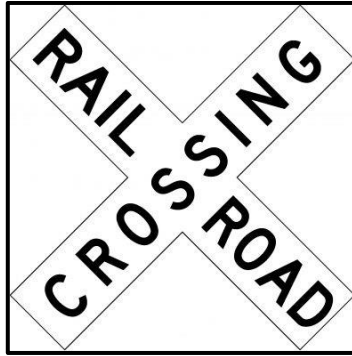


Figure 1: Crossbuck (R15-1)

1. A grade crossing crossbuck assembly shall consist of a crossbuck (R15-1) sign, and a Number of Tracks (R15-2P) plaque if two or more tracks are present, that complies with the provisions of Section 8B.03, and either a YIELD (R1-2) or STOP (R1-1) sign installed on the same support, except as provided in Paragraph 8 which states that: If a YIELD or STOP sign is installed for a crossbuck assembly at a grade crossing, it may be installed on the same support as the crossbuck sign or it may be installed on a separate support at a point where the highway vehicle is to stop, or as near to that point as practical, but in either case, the YIELD or STOP sign is considered to be a part of the crossbuck Assembly. If used at a passive grade crossing, a YIELD or STOP sign shall be installed in compliance with the provisions of Part 2, Section 2B.10.
2. Standard: A Railroad-highway Grade Crossing Advance Warning (W10-1) sign (
3. **Figure 2** below) shall be used on each highway in advance of every railroad-highway grade crossing, and every highway-Light Rail Transit (LRT) grade crossing.



Figure 2: Grade Crossing Advance Warning Sign (W10-1)

2.1.1.2 TCD Compliance at Railroad-Highway Grade Crossings

In the U.S., there are primarily three types of control devices present at grade-crossings: pavement markings & crossbucks, operating flashing lights, and flashing lights with lowered gates; how a driver should comply with them (i.e., the drivers' need to yield or stop if needed) is dictated by the UVC and must be followed by road users as follows:

- 1) A crossbuck is a type of YIELD sign: the driver should be prepared to stop at least 4.5 m (15 ft) before the near rail if necessary, unless and until the driver can make a reasonable decision that there are no trains in hazardous proximity to the crossing, and it is safe to cross.

- 2) Operating flashing lights have the same function as a STOP sign: a vehicle is required to stop completely at least 4.5 m (15 ft) short of the near rail. Then, even though the flashing lights may still be operating, the driver is allowed to proceed after stopping (subject to State or local laws), when safe to do so.

- 3) Flashing lights with lowered gates are equivalent to a red vehicular traffic signal indication: a vehicle is required to stop short of the gate and remain stopped until the gates go up.

In combination with enforcing the law, State and local governments are responsible for overseeing the installation of active warning devices at grade crossings (such as flashing lights and gates), as well as passive devices (such as stop signs and yield signs). In fact, railroads cannot install highway traffic control devices on public roads without the consent and permission of appropriate government authorities (FHWA Grade Crossing Handbook, 2002). If pedestrians and bicyclists are frequent users of the crossing, the MUTCD provides guidance for supplemental signage to address their safety.

2.1.2 Warning Devices

One of the earliest forms of grade crossing safety systems required a watchman to flash a red lantern from side to side to alert motorists of a train's proximity to a railroad-highway grade crossing and their need to stop (O 2011). This system became inefficient with the increase

in train frequency and grade crossing fatalities. As a result, the wigwag shown in **Figure 3** below was developed by Southern California's Pacific Electric. The wigwag signal worked by alerting drivers of an approaching train by performing a pendulum-like motion prior to train arrival. While the pendulum swung, the solid red light placed in the center of the device would turn on and remain for the duration of the motion. The placement of the wigwag varied, some were on the side of the road, others cantilever mounted. Because of changes in signaling rules, the wigwag was rendered obsolete for new installations in 1949, but grandfathering laws allowed them to remain until upgrades to the crossings at which they were installed were necessary. In 2004, the FRA reported that there were 1,098 grade crossings around the country, confirmed as having 1 or more wigwags as their warning device (Wikipedia, 2011).



Figure 3 Cantilever mounted wigwag signal Photo credit: Dan Haneckow

The successor to the wig wag is the alternating red flashing lights mounted on what is known as the crossbuck, frequently combined with automatic gates **Figure 4** (below). According to the FRA, 25 percent of all public grade crossings in the U.S. are protected with gates, 18 percent of the crossings are protected with flashers or another active device and 44 percent have at least a crossbuck (0 2013). Warning devices found at railroad-highway grade crossings can be classified as either passive or active.

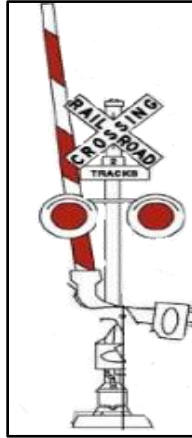


Figure 4 : Flashing Light With gate in Upright Position and Crossbuck

2.1.1.3 Passive Warning Devices

Passive warnings can be in the form of a sign or pavement marking. The purpose of the passive device is to alert the driver of a possible condition ahead on the road regardless of the presence of a train. According to the MUTCD “Passive traffic control systems, consisting of signs and pavement markings only, identify and direct attention to the location of a grade crossing and advise road users to slow down or stop at the grade crossing as necessary in order to yield to any rail traffic occupying, or approaching and in proximity to, the grade crossing.” An example of a passive warning device is the railroad-highway crossing in the form of an X on a yellow background, previously discussed.

2.1.1.4 Active Warning Devices

Active warning devices alert the driver of the actual presence of a train at the crossing. The most common type of active warning device is the alternating red flashing lights mounted on a crossbuck and frequently combined with the use of gates.

FRA statistics show that in 2009, the U.S. had 136,041 public at-grade crossings. Of these crossings, approximately 42,301 have gates, 22,039 have flashing lights, and 1,196 have highway traffic signals, wigwags, and bell (FRA, 2009).

2.1.3 Grade Crossing Placement

The FRA's rail safety regulations require that crossings be separated or closed where trains operate at speeds above 125 mph per law 49 CFR 213.347(a). Additionally, if train operation is projected at FRA track class 7 (111 - 125mph) an application must be made to the FRA for approval of the type of warning/barrier system that is to be used. The regulation does not specify the type of system, but allows the petitioner to propose a suitable system for FRA review. Grade crossings are prohibited on the Northeast Corridor of the U.S. if maximum operating speeds exceed 95 mph (0 Guide on Traffic Control Devices at Railroad-Highway Grade Crossings, 2002).

2.1.3.1 Grade Separation & Crossing Closure

The decision to grade separate (the crossing is placed either above ground or underground) a railroad-highway crossing is primarily a matter of economics. Investment in a grade-separation structure is long-term and impacts many users. Such decisions should be based on long-term, fully allocated life-cycle costs, including both highway and railroad user

costs, rather than on initial construction costs (O Guide on Traffic Control Devices at Railroad-Highway Grade Crossings, 2002).

The national policy on grade crossing closure is to eliminate unneeded and redundant crossings. Grade crossings should be limited to those where a need can be demonstrated and the need outweighs the hazards of keeping the crossing open. The Institute of Transportation Engineers (ITE) provides a set of criteria that may be used for quantifying the candidacy of a grade crossing for closure via the Traffic Control Devices Handbook (Ogden, 2007).

2.2 Grade Crossings in the Literature

Over the last four decades, a number of initiatives have targeted the improvement of crashes at grade crossings. From Operation Live Safer which brings education into schools, to the FRA most recent campaign of “Stop Because Trains Can’t,” the U.S. public has been bombarded with messages that not only caution but also instruct the driver on what to do in the vicinity of train crossings. In 2016, the FRA established partnerships with mapping/software companies such as Google Maps, Garmin, Nuvi, and iMaps in an attempt to incorporate a warning system which alerts drivers of the presence of a crossing while engaging with navigation applications (NYT, 2016).

While the aforementioned campaigns have had an impact on reducing the number of incidents at grade crossings, the number of deaths caused by train-vehicle collisions still remains a pressing issue. In 2014, 239 people were killed and 763 people were injured in grade crossing incidents in the U.S (FRA, 2015). Addressing grade crossing safety takes a multi-disciplinary approach from the engineering, enforcement and education communities. This literature review centers on addressing previous work conducted mostly in the realm of human factors concepts as they relate to traffic safety engineering issues, particularly addressing grade crossing safety. The following studies provide a foundational background to achieve the goals of this dissertation.

There are certain human factor considerations which must be taken into account when developing appropriate measures for alerting drivers of the presence of a train: 1) the driver must first be alerted that he is approaching a grade crossing in a way that calls for the immediate initiation of certain perceptual or driving patterns, and 2) the driver would ideally be alerted of the actual arrival of a train to the crossing (Hulbert, 1968). Addressing human performance characteristics such as short attention span and boredom poses a challenge to the traffic safety community. The U.S. Government's Distraction website reports that in 2014, 3,179 people were killed, and 431,000 were injured in motor vehicle crashes involving distracted drivers (U.S. DOT, 2014) Distraction is challenge that impacts every aspect of our lives, particularly behind the wheel. While the effectiveness of grade crossing warning devices on driver's behavior at grade crossings has been studied extensively (Horton et al., 2016)(Caird et. al., 2000)(Lenné et al., 2011), more information is needed on how these devices perform under circumstances of distraction.

One of the most comprehensive studies to look at the contribution of human factor characteristics on crashes at grade crossings was performed by Caird et al., (2002). Using data from the Canadian Transportation Safety Board's Rail Occurrence Database System researchers performed qualitative analyses of crash narratives. The narratives were searched using a taxonomy developed for the purpose of this study in which human factors contributors to railroad-highway grade crossing accidents were identified. The study identified: unsafe acts, individual differences, train visibility, passive signs and markings, active warning systems, and physical constraints, as the primary categories of accident contributors. The analysis was used to recommend countermeasures based on patterns of probable cause.

The study examined over 300 grade crossing crashes and identified human factor contributors to railroad-highway grade crossing incidents. Distraction was associated with 39 narrative crashes for the period of 1990-2001. The number one cause of distraction type among these crashes was the failure to see signals/train on approach; twelve (12) crashes identified a driver having not seen the crossing protection and as a result made no attempt to stop. The second cause of distraction was late detection of train. Seven drivers reported not seeing the train until the last minute and then attempting a failed last-minute stop. The third identified cause of distraction was talking on a cellular device – 7 narratives stated that the driver was engaged in a cell phone conversation. Other identified distractions include – internal cognitive distractions such as the driver reporting worry or preoccupation while driving. Changing the radio was found to contribute to 1 crash.

In addition to identifying distractions, the researchers analyzed current signs and signal systems and evaluated them in terms of perceived effectiveness such as the number of reductions in violations, accidents, and injuries. Important findings from this analysis reveal that crossing familiarity and an expectation that a train will not be present have the potential to push drivers into a feeling of complacency when crossing and, as consequence, have poor looking habits. The report also shows that active crossings equipped with automatic warnings to prevent train-vehicle crashes have the greatest potential of reducing incidents, injuries and fatalities. On the passive crossing side, the study found that stop signs at railroad-highway grade crossings are frequently disregarded by drivers.

The placement of stop signs at grade crossings has been a contentious subject in the U.S. In 1992, the Federal Highway Administration (FHWA) in partnership with the FRA made public a final rule for when the use of a Stop and Yield sign at a grade crossing is appropriate (U.S. DOT 1993). In the state of Kansas for example, it is policy of the Kansas Department of Transportation to include a stop sign at the grade crossing and a yield on the roadway approach; this practice ensures that in the event a driver is stopped at the sign (before entering the crossing) a judgement can be made as to whether there is enough clearance space for the stopped driver to proceed (Rys et al., 2009). Although allowed by federal regulations, the use of stop signs is not common practice and very little is known on how this practice can benefit drivers who encounter crossings in with various circumstances (i.e., suburban, urban settings) as well as crossings with varying geometric features.

The opposition for the use of stop signs at grade crossings is supported by previous research. A driver simulator study conducted by Lenné et al., (2011) compared driver behavior at grade crossings with three different TCD configuration: one crossing equipped with flashing lights, another crossing with a traffic signal, and a passive, stop-controlled crossing. In addition, the flashing light and traffic signal scenarios were supplemented with additional warning sign 150m (500ft) in advance of the all, and the stop sign condition was supplemented with a warning sign 210m (689ft) in advance of the crossing; all crossings were associated with an oncoming train.

The study measured the mean vehicle speed on approach at each grade crossing and the participant's crossing compliance. Comparative analysis showed that the mean vehicle speed on approach to the grade crossings decreased most rapidly early on (further back from the crossing) when drivers encountered flashing lights rather than traffic signals. Stop sign scenarios showed the lowest speed on approach and also accounted for the highest number of non-compliant events, meaning that drivers did not come to a full stop before proceeding to cross. Of note in this study is the fact that although participants slowed down as they approached the grade crossing, this did not translate to a higher rate of compliance – even with advance warning.

Although the use of a supplemental sign did not help drivers in the Lenné study perceive the potential danger ahead, these findings do point to the need for innovative ways to improve TCD configuration at grade crossings. It is possible that the use of pavement markings could potentially improve driver's compliance behavior at non-gated active crossings. Previous

research in the area of pedestrian safety has proven that the use of pavement markings in advance of a non-intersection pedestrian crossing can improve driver's scanning and compliance behavior (Gómez, 2011); (Garay-Vega 2008), the question is whether this benefit translates to grade crossing environments, especially when a driver is distracted.

2.2.1 Driver Distraction

Each day in the United States, more than 9 people are killed and more than 1,060 people are injured in crashes that are reported to involve a distracted driver (CDC, 2013). Distracted driving is driving while performing another activity that takes your attention away from driving. The Insurance Institute for Highway Safety reported that when drivers engage in a cell phone task while driving, there is a four-fold increase in the likelihood that a crash serious enough to require medical attention can happen (McEvoy et al., 2005). This study also concluded that using a hands-free phone was not any safer than hand-held.

Distractions can be classified in three main categories:

- **Visual:** taking your eyes off the road;
- **Manual:** taking your hands off the steering wheel; and
- **Cognitive:** taking your mind off of the driving task.

Distracted driving can include activities such as eating, carrying on a conversation with a passenger, using a cell phone, texting, and looking at things outside the vehicle. Logically, it can

be inferred that if a driver is looking inside the vehicle he/she is not looking at the road. Other in-vehicle activities such as changing radio stations or using a navigation system (GPS) have been proven to cause driver distraction and cause the driver to take longer glances away from the forward roadway (Chan et al., 2008);(Horrey & Wickens, 2007);(Klauer et al, 2006). In fact, a simulator study on the effects of in-vehicle distraction reported that the 22 percent of the longest in-vehicle glances while the driver performed a secondary task accounted for about 86 percent of the observed crashes (Horrey & Wickens, 2007). While the aforementioned activities degrade driver's attention, texting while driving has become the most alarming task a driver can engage in while driving because it combines all three types of distraction (CDC, 2013) (Samuel et al., 2011).

While it is clear that in-vehicle distractions can lead to failures to see either an advance sign or a warning device, it may be less clear that cognitive distractions can lead to such failures. However, they can do so in two separate ways: First, the cognitively distracted driver scans more narrowly, therefore making it less likely that a sign or warning device in the periphery will be fixated. Second, even if the cognitively distracted driver glances at a sign or warning device, the fact the driver is cognitively distracted can decrease the likelihood that the driver actually attends to the information he or she is fixating on (Taylor et al, 2013). Looking further into the literature beyond "regular" motorists, the issue of distraction and inattentiveness at railroad-highway grade crossings expands to Commercial Motor Vehicle (CMV) drivers as well.

A study conducted at the Volpe Center reviewed and coded 3,171 grade crossing events involving commercial motor vehicle drivers (CMV) (Ngamdung & daSilva, 2012). The CMV

drivers were provided with heavy vehicles instrumented for the Integrated Vehicle Based Safety System (IVBSS) Heavy Truck Field Operational Test (FOT) study sponsored by the U.S. DOT National Highway Traffic Safety Administration (NHTSA). Each heavy vehicle was equipped with a system which collected data related to vehicle performance, driver performance, vehicle location, and driving environment. Video data was also collected from five cameras that were installed inside each research vehicle. The cameras were placed strategically to capture the forward view, driver's face, cabin/instrument panel, exterior left side of the vehicle, and exterior right side of the vehicle.

Analysis of looking behavior on approach to the crossing demonstrated that drivers looked at least one way at or on approach to the crossing about 61 percent of the time. From the 3,171 grade crossing events 91 percent (about 2,891) of these crossings were equipped with active warning devices. The results of the data revealed that on average, the participant drivers were likely to engage in secondary tasks about 21 percent of the time when traveling over the grade crossing. The most frequently observed (205 crossing events) secondary task involved being on the phone either talking or listening. The study also revealed that "younger drivers", which for the purpose of the study was defined to be drivers less than 22 years in possession of the Commercial Drivers' License (CDL), were more likely to engage in performing a secondary task during a crossing event than were older drivers.

The study went further and analyzed the distribution of looking behavior by warning device (**Figure 5**). What stands out about this figure is that approximately, 59 percent of drivers who looked at least once at crossings equipped with passive devices almost looked as often as

they did with active crossings - 60.7 percent. The glance behavior for passive devices is high but not surprising, since noncompliance is highest for passive devices than for active devices; which means drivers may be looking just as much with passive devices but with the intention of crossing as soon as possible rather than stopping.

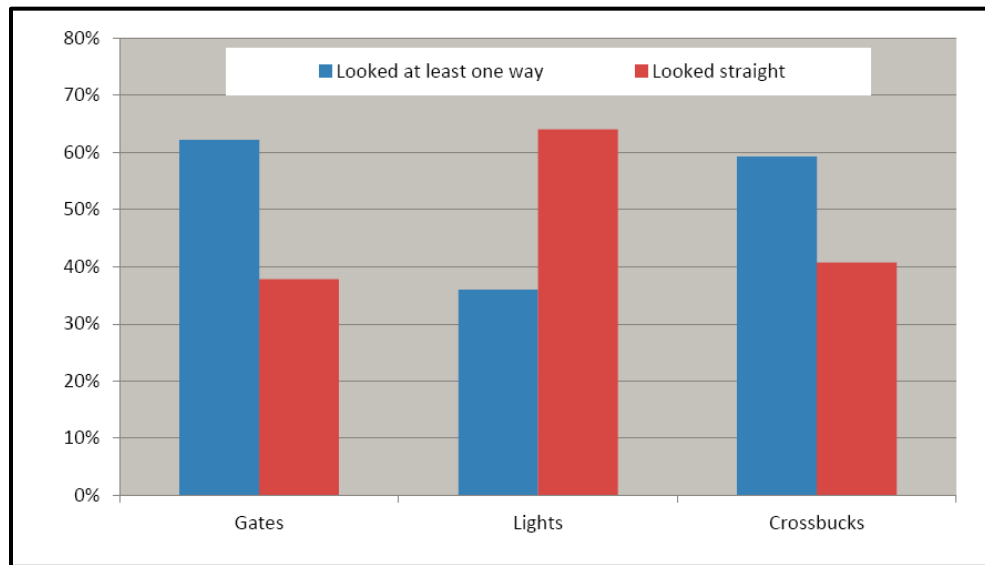


Figure 5: Distribution of Looking Behavior by Warning Type, U.S. DOT

The Volpe Center study identified 43 crossing device activations (e.g. lights turned on, gates descended); 38 out of 43 crossing activations were violated by participant drivers. **Table 1** below provides a breakdown of the violations according to warning device.

Table 1 Distribution of Violations by Warning Devices

Warning Devices	Number of Activation Events	Number of Violations by Research Vehicle	Number of Violations by Other Vehicles	Total Violations
Gates	37	3	31	34
Lights	4	0	3	3
Crossbucks	2	1	0	1
Total	43	4	34	38

Based on the violation (non-compliance) results, the study concluded that drivers were most likely to look at least one way at crossings equipped with gates and least likely to look one way at crossings equipped with lights. These findings are in line with findings by Wigglesworth, 1979 which indicated that accident frequency for commercial motor vehicle drivers at flashing-light crossings is more than that of gated crossings.

The Wigglesworth study analyzed the train conductor's perception of CMV drivers and surveyed CMV drivers regarding their behavior at grade crossings. While train conductors perceived CMV drivers as risky and impatient, the CMV drivers admitted to "suffering a lapse of concentration, resulting in them failing to follow appropriate safe crossing behavior at level crossings". While this study did not have cameras to monitor the CMV drivers' behavior, it can be safe to assume that if a driver, whether commercial or not feels confident in their ability to detect an approaching train, they will be more willing to engage in distracting activities such as cell phone conversation, thus not paying as much attention to the warning devices in the driving environment and ultimately causing the driver to engage in last-minute glance and vehicular behaviors to avoid a crash.

2.3 Inattentional Blindness – The Phenomenon of “Look but did not see”

In the Caird et al., study previously discussed, the number one cause of crash under the category of driver distraction was – “Did not see signals/train at all”. The drivers identified in the crash narratives had no explanation as to why this happened, since according to their accounts, they were not involved in a secondary task at the time of the crash. It is possible then, that what these drivers experienced was a case of Inattentional blindness.

Inattentional blindness refers to an event in which an individual fails to recognize an unexpected stimulus upon which he or she is gazing (Mack & Rock, 1998). Inattentional blindness suggests that this phenomenon can occur in all individuals, independent of cognitive deficits. Mack and Rock put forward the idea that it is simply impossible for one to attend to all visual stimuli and as a result “temporary blindness” can take place.

There are a set of criteria that an event must meet in order to qualify as an inattentional blindness episode):

1. The observer must fail to notice a visual object or event,
2. the object or event must be fully visible,
3. observers must be able to readily identify the object if they are consciously perceiving it, and;

4. the event must be unexpected and the failure to see the object or event must be due to the engagement of attention on other aspects of the visual scene and not due to aspects the visual stimulus itself.

Individuals who experience inattentional blindness are usually unaware of this effect, which can play a subsequent role on behavior. For example, previous research has proven that using either hands-free or hand-held cellular devices while driving results in the failure of attention to explicitly capture other noticeable and distinctive objects, leading to significantly delayed reaction times, as well as inattentional blindness (Horrey & Wickens, 2006).

Grade crossings are complex environments which create perfect “look but did not see” situations (Richards & Heathington, 1986). Drivers do not always understand the meaning of warnings (Hulbert & Burg, 1979); (Richards & Heathington, 1986). Poor driver comprehension coupled with a secondary task while driving could be disastrous. As evidence, a driving simulator study (Strayer & Johnston, 2001) showed that such might occur; drivers missed red traffic signals more frequently when talking on the cell phone than when off the cell phone. Researchers found that participants engaged in cell phone conversations during a tracking task were more likely to react more slowly when they encountered a traffic signal or to miss traffic signals entirely. The effects were similar for both hand held and hands-free phone configurations.

The issue has also been studied beyond the simulated environment. An on-road experiment where 21 drivers drove around an 8 kilometer (km) city route while performing

demanding cognitive tasks using a hands-free driving mode looked at cognitive distractions while driving (0). The participant drivers were presented with three conditions: easy cognitive task, no additional cognitive task and difficult cognitive task. This study investigated the impact of demanding cognitive tasks without visual/manual distraction on driver behavior and performance. The primary measures of interest were indices of drivers' visual behavior with respect to safety-relevant objects in the driving environment such as intersections and traffic lights. Braking behavior patterns were also collected as well as participant's own self-evaluations with respect to safety, workload, and distraction. The results from this study show that when on-road drivers are engaged in demanding tasks, they are looking less often at the lights and the intersection environment ahead. The data in this study also indicates that participants reduced their glances to traffic signals and their monitoring of the area around the intersection.

The findings previously discussed give any reasonably safety-conscious person the urge that something must be done soon in order to improve the current condition of grade crossing safety. After an initial consideration of the research to date, the regulations governing grade crossing safety and the prevalent concern for safety at grade crossings, the following research experiments were developed, conducted and analyzed to accomplish the goals of this dissertation.

CHAPTER 3

EXPERIMENT 1: A SIMULATOR EVALUATION OF TRAFFIC CONTROL DEVICES AT GRADE CROSSINGS

The current traffic control device configuration we see today was developed by the American Association of Railroads (AAR) almost ninety years ago, (Fambro, 1990). The goal of the first experiment was to evaluate the signage currently in place today at most non-gated grade crossings, mainly the advance warning sign and flashing lights previously discussed in Chapter 2. With the current increase in drivers performing distracting tasks while driving, it was important to first get a sense for how well these traffic control devices hold up to modern day drivers and favorite life activity – multitasking. The following experiments were performed at the Arbella Insurance Human Performance Lab (HPL), housed in the Department of Mechanical and Industrial Engineering, at the University of Massachusetts Amherst.

3.1 Methodology – Experiment 1

3.1.1 Participants

The first research experiment predominantly recruited research participants from the Pioneer Valley area in the Western part of the State of Massachusetts. Recruitment information was vastly disseminated via social media, mass electronic mail (email) and flyers posted throughout the Town of Amherst. Interested participants were provided with a link to a Google form where they submitted their age, sex, contact information and available times for

participating in the study. Participants were then contacted by their preferred method of communication, as indicated on the form, and their participation was confirmed with an email stating the date and time of their appointment, as well as driving directions to the Arbella Human Performance Lab. Each research participant was scheduled for a one time, one-hour slot and compensated twenty (\$20) dollars for their time if they completed the study; participants who were not able to complete the simulation received partial compensation for their time. In order to participate in the study, participants had to be at least 19 years old and possess a valid U.S. driver's license (including Puerto Rico and Hawaii).

A total of fifty-three (53) participants were enrolled in experiment 1; 23 participants identified as females and 30 participants identified as males. There were forty-six participants used for the analysis. The average age for participants in experiment 1 was 28.2 years old ($SD = 7.0$) with an average driving experience of 10.57 years ($SD=7.32$).

3.1.2 Experimental Procedure

Upon arrival to the HPL, participants were greeted and provided a folder labeled with a unique randomized five-digit code that was used to protect the participants' identity throughout the data collection/analysis process. The folder contained three documents: a consent form (**APPENDIX A**) which provided the participant with more information on the study, their rights as a participant and their voluntary consent in the form of a signature. The participant was also provided with a demographic questionnaire (**APPENDIX B**) which collected basic demographic information such as date of birth, years of driving experience, ethnicity, and a non-required, voluntary question on their most recent use of a cell phone while driving. Lastly, before

beginning the experimental portion of the study, participants were provided with a Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) (**APPENDIX C**) which assessed the likelihood that the participant may experience any sort of *simulator sickness* or physical discomfort caused by their interaction with the driving simulator. Once the paperwork was completed, and any questions answered, participants were ushered to the vehicle and provided with further instructions.

The first and most important step in setting up the participant for a successful driving simulator experience was ensuring the participant felt comfortable in this newfound driving environment. This task was achieved by providing ample information on the use of the car (i.e., practicing braking, adjusting the seat to their level of comfort, looking around the vehicle) and answering any questions before beginning a practice drive.

Every participant had the opportunity to interact with the vehicle via a *practice drive* or a simulated drive where no experimental data was collected from the participant. The purpose of the practice drive is twofold: first, the drive exposes the participant to the various elements of the virtual environment and second, the drive allows the participant to become comfortable with operating the vehicle. For the purpose of this study, the practice drive included exposure to two important elements of the study – a large vehicle ahead, and a grade crossing with flashing lights (discussed in detail later in the document). It was also important for the participant to be exposed to on-screen directions for successful navigation of the drives.

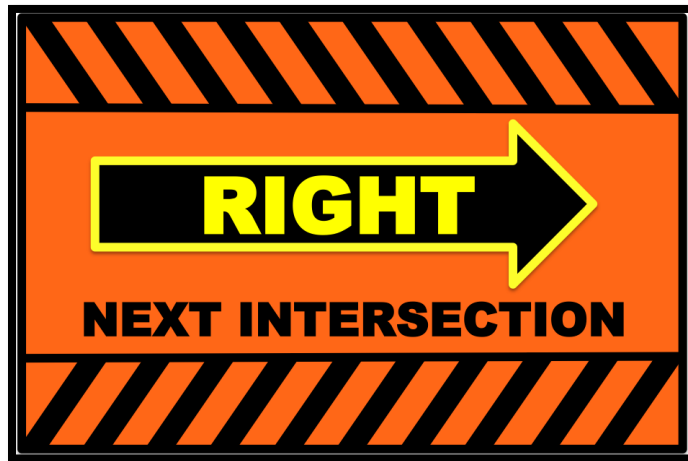


Figure 6: Sample Navigation Sign in Driving Environment

Participants were randomly assigned to three groups: control (driving with no distraction), in-vehicle task (changing the radio), or cell phone (performing a mock cell phone conversation). For participants assigned to perform a distracting task of either an in-vehicle task or a mock cell phone conversation while driving, a practice segment for their respective assignment was completed prior to the start of the experimental drives. For the in-vehicle task, participants were asked to interact with the car's FM/AM radio by changing the radio station a few times using the radio's "up" and "down" buttons; participants were not allowed to use the pre-set radio buttons for this task. For participants assigned to perform the mock cell phone conversation, a practice segment was also conducted to familiarize the participant with the task of listening and answering to the prompts given (discussed in a later section).

Once the practice drive and task familiarization were completed, participants were introduced and retrofitted with an *eye tracker* – a pair of cameras mounted on safety goggles and further discussed in Section 3.1.4.

Upon the completion of the study, participants were asked to complete the second part of the SSQ which asked participants to rank their post-experimental physical discomfort. Participants were debriefed as to the nature of the study, and ended their participation by receiving payment and signing a form for payment receipt.

3.1.3 Driving Simulator

Tasked with the successful creation of experimental *drives* or simulated course most geographically similar to that of Western Massachusetts, a full-cab driving simulator **Figure 7** was used to achieve this goal. The virtual environment or *simulator drives* were developed, tested, and ran using software developed by Real Time Technologies, Inc. (RTI).

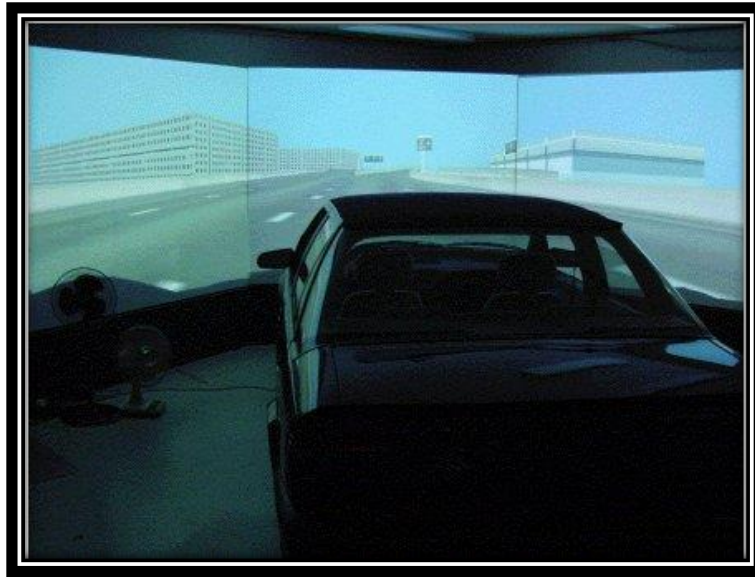


Figure 7: Driving Simulator

The virtual world was rendered by three projectors on three screens (left, center, and right). The center screen also projected a simulated rear-view mirror; the left and center screens also projected simulated side mirrors respectively. Real-time images were shown on each of these mirrors emulating those in a real vehicle. The virtual world was projected at a refresh rate of 60 Hz and a resolution of 1400 by 1050. The individual screen images themselves were generated with four simulator servers which parallel process the images projected to each of the three screens using high end multimedia video processors. Three screens allow 150 degrees of vision in the horizontal direction and 30 degrees in the vertical direction.

Participants drove the fixed-base simulator, composed of a full size 1995 Saturn sedan in which all vehicle controls are fully operative. The simulator also employs a surround sound audio system. This system provided realistic wind, road and other vehicle noises with appropriate direction, intensity and Doppler Shift. For the grade crossings, participants

experienced the sounds of steel-on-steel train wheels as they witnessed a train completing a crossing.

3.1.4 ASL Eye Tracker

A portable lightweight mobile eye tracker developed by Applied Science Laboratory (ASL) was used to collect eye movement data for each participant driver **Figure 8**. Previous research has shown that the use of an eye tracker can provide information about where a driver is looking which can be helpful to transportation engineers in improving the use of traffic control devices (Garay-Vega, 2008) (Gómez et al., 2011). The eye tracking device is made up of a lightweight optical system consisting of an eye camera and a color scene camera mounted on a pair of safety glasses. The images from these two cameras are incorporated and recorded externally on a remote recording system **Figure 9**. The remote recording system processed and converted the eye movement data to a crosshair, representing the driver's point of gaze. This eye information was overlaid upon the scene video recorded during the drive. The information collected with the eye tracker provided a record of the driver's point of gaze on the driving scene while in the simulator.

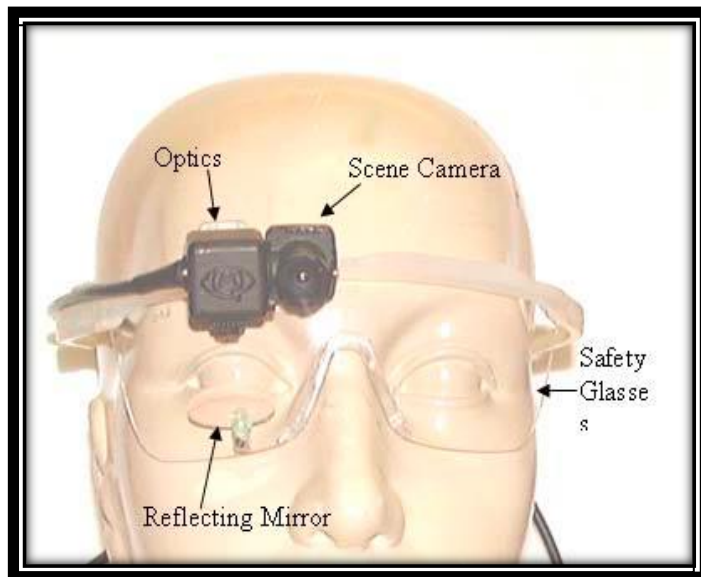


Figure 8: ASL Eye Tracker

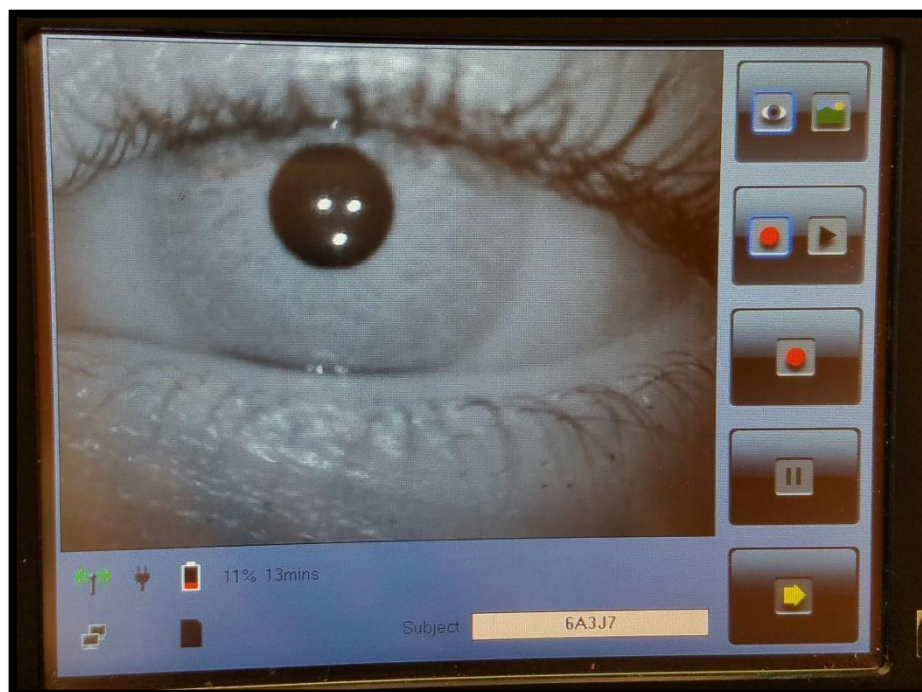


Figure 9: Eye tracker external recording device depicting perfect eye calibration

3.1.5 Traffic Control Devices for Evaluation

The main focus of experiment 1 was the evaluation of the current signage at grade crossings. It was essential to understand driver's behavior and reaction under the influence of distraction to the most commonly used TCD's – the advance warning sign previously shown in **Figure 2**, and the crossbuck and flashing lights, shown in

Figure 10. The placement and graphical rendering of these devices in the virtual driving environment were built to scale, according to the MUTCD standards previously discussed in Chapter 2. It is important to note that for the purpose of this experiment, the bell sound frequently coupled with flashing lights were purposely turned off. The reason for this decision, was to simulate the worst condition possible - a driver who may be distracted by listening to the radio or involved in a cell phone conversation with their car windows up. In addition, modern vehicles frequently have high internal ambient noise, fan motors running and other noises which in many cases make it impossible to hear the bell sound at the crossings.



Figure 10: Crossbuck (R15-1)

3.1.6 Simulator Drives

Using the RTI software previously described, twelve occurrences or *scenarios* at grade crossings were created to evaluate driver's performance as they traversed these crossings. The creation of these scenarios centered on varying four key safety factors as participant drivers approach a crossing:

1. The presence or absence of a vehicle ahead of the driver,
2. The visibility of the advance warning sign (visible or obscured),
3. The visibility of the crossbuck and the flashing lights (visible or obscured),
4. And lastly, the state of the flashing lights (ON/OFF).

The twelve scenarios were divided in two drives with six (6) scenarios in each drive. Most participants completed both drives in a timeframe of ten (10) to fifteen (15) minutes. The two drives referred to as a *Bus Drive (B)* where the large vehicle ahead of the driver in the first and last scenario was represented by a city bus or a *Truck Drive (T)* where the large vehicle ahead of the driver in the first and last scenario was represented by a truck. Both drives were nearly identical environmentally and mostly varied in the happenings at each crossing, this included the type of vehicle the participant was exposed to at each scenario. Every participant drove a designated route as shown in **Figure 11**. Participants were randomly assigned to drive one of the drives first, rest for a few minutes and then perform the second drive. For example; if a participant was assigned to drive the Bus Drive first, they would then drive the Truck Drive second, and vice versa. Detailed descriptions of each scenario for the Truck and Bus Drives and scenarios order of appearance can be seen in **Table 2** and **Table 3** respectively.

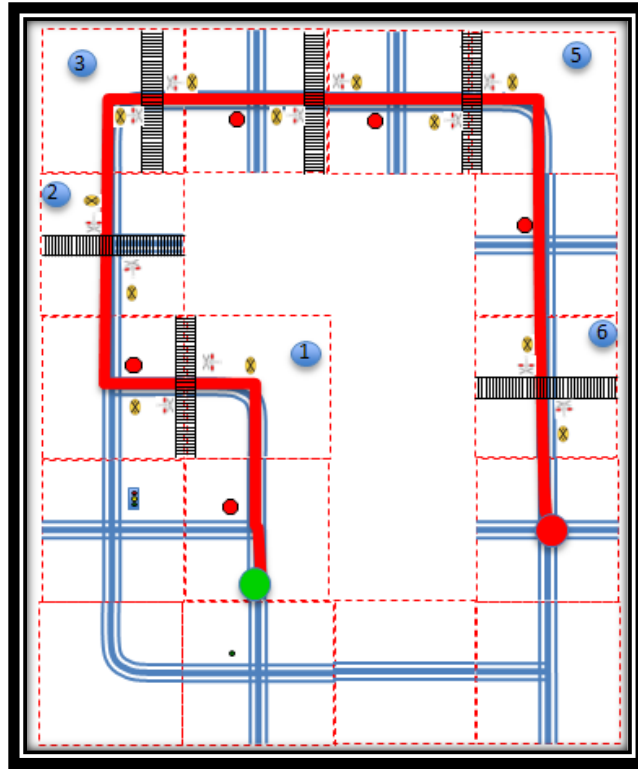


Figure 11: Bus Drive Route

Table 2: Scenario Descriptions for Bus (B) Drive

Scenario Sequence & Abbreviation	Scenario Description
B1 - BA,V,OFF (BnT)	Rail Crossing with Bus Ahead, Advance Sign Visible, Flashers Visible, Flashers OFF
B2 - CA,V,OFF	Rail Crossing with Car Ahead, Advance Sign Visible, Flashers Visible, Flashers OFF
B3 - NCA,V,ON	Rail Crossing with No Car Ahead, Advance Sign Visible, Flashers Visible, Flashers ON
B4 - CA,O,OFF	Rail Crossing with Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF
B5 - NCA,O,ON	Rail Crossing with No Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers ON

T8 - CA,V,ON	Rail Crossing with Car Ahead, Advance Sign Visible, Flashers Visible, Flashers ON
T9 - NCA,O,OFF	Rail Crossing with No Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF
T10 - CA,O,ON	Rail Crossing with Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers ON
T11 - NCA,V,OFF	Rail Crossing with No Car Ahead, Advance Sign Visible, Flashers Visible, Flashers OFF
T12 - TA,O,OFF (TT)	Rail Crossing with Truck Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF

3.1.7 Scenario Design & Descriptions

The twelve scenarios designed to evaluate driver behavior during experiment 1, can be classified into three categories: *Car Ahead (CA) Scenarios*, were scenarios where the participant witnessed a car pull ahead as they approached a grade crossing. Similarly, in *Car Not Ahead (CNA) Scenarios*, there were no vehicles in front of the participant as they drove towards a crossing, and lastly, *Large Vehicle Ahead* scenarios where the large vehicle ahead was either represented by a bus in the Bus Drive or a truck in the Truck Drive respectively. In addition, four of these twelve scenarios have been categorized as *Scenarios of interest* (discussed later in the document) because the combination of factors used to create these scenarios –TCD visibility, state of lights (ON (Flashing)/ OFF (Not Flashing) and presence or absence of a vehicle ahead can create complex situations for drivers when making decisions as they approach a grade crossing. In addition, drivers’ compliance performance was scored at these crossings.

3.1.7.1 Scenarios of Interest: Large Vehicle Ahead

The safety threat caused by the presence of a large vehicle ahead has been widely studied (Garay-Vega, 2008) ;(Gómez et al., 2014). Large vehicles such as truck or buses ahead of a driver can impact the drivers' ability to recognize potential threats ahead such as pedestrians attempting to cross a roadway (Van Houten, 2011), or flashing lights alerting drivers of an approaching train.

In order to analyze the impact of a large vehicle ahead, participants either saw a truck or a bus ahead, as they approached a set of crossings. For the Truck Drive scenarios previously described in **Table 3**, a truck appears in the first scenario and stops for flashing lights – Truck no Trick (TnT) and a few seconds later, a train begins to cross; the traffic control devices at this crossing are fully visible to the driver. For this “no trick” scenario, the driver is expected to come to a full stop behind the truck until the train has cleared the crossing, the lights turn off and the truck proceeds forward. A top view of the first scenario in the Truck Drive is shown in

Figure 13.

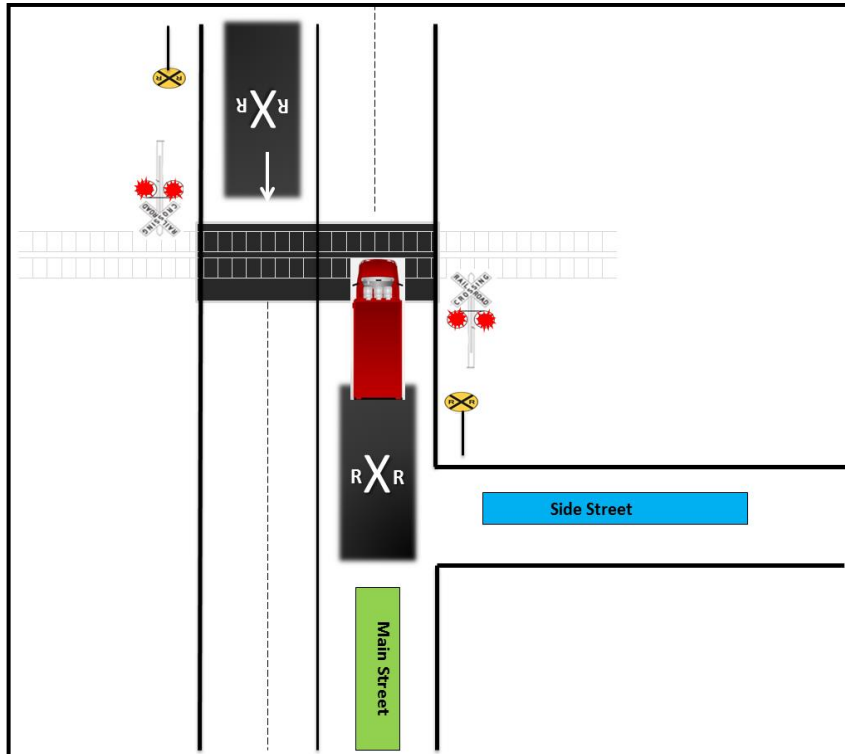


Figure 13: Scenario Plan View for Truck no Trick Scenario

The truck makes an appearance once again during the last scenario of the drive. In this Truck Trick (TT) scenario, the traffic control devices are obscured by the presence of vegetation. The participant is behind the truck, the truck goes over the crossing and simultaneously, the flashing lights turn on at the last minute **Figure 14**. This scenario is a scenario of interest because the distracted participants are expected to follow the truck closely and miss the flashing lights if not paying attention, thus setting the driver to be “tricked”.



Figure 14: Truck Trick Scenario – Lights Turn On as Truck Goes Over Crossing

Similarly, for the first scenario of the Bus Drive – Bus no Trick (BnT), the participant sees a bus pull in front and make a stop at the grade crossing while the driver is behind the bus **(Figure 15)**. In this case, the bus is not stopping at the crossing because the lights are turned on, but due to Federal regulations which require that all buses stop at grade crossings. The bus proceeds forward after a few seconds, and moves from the participants' way. **Figure 16**, shows a top view of the same scenario.



Figure 15: Driver Fixation on Bus Stopped during Bus No Trick Scenario

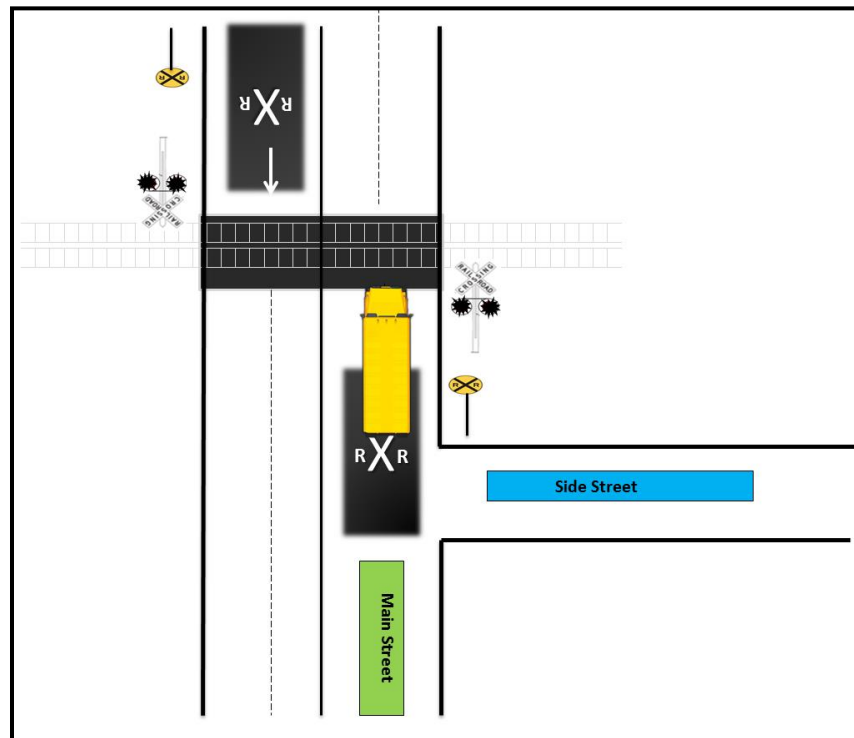


Figure 16: Scenario Top View for Bus Stopped at Crossing with Flashing Lights OFF and Advance Sign Visible

The bus appears again during the last scenario of the Bus Drive. The *Bus Trick Scenario* – (BT) presents the driver with obscured traffic control devices on approach to the crossing. The bus pulls in front of the participant once again, makes a stop (similar to what the participant has already seen in the first scenario) but this time, as the bus pulls forward, the lights turn on last minute for the driver thus also creating a “trick”. For this scenario, participants performing a distracting task are expected to follow closely behind the bus and miss the flashing lights when they turn on at the last minute.

3.1.7.1.1 Road Geometry Considerations

Among the twelve (12) scenarios of interest, there were four scenarios which were of utmost importance in order to truly measure participant driver’s behavior at these crossings. These *Scenarios of Interest* described in **Table 4** below. What is key about these scenarios is that, in addition to the driver’s glance behavior, yield/stopping behavior was also scored at these crossings.

Table 4: Scenarios of Interest – Road Geometry Features

Scenario of Interest	Scenario Description	Road Geometry Feature
----------------------	----------------------	-----------------------

B3 - NCA,V, ON	Rail Crossing with No Car Ahead, Advance Sign Visible, Flashers Visible, Flashers ON	Crossing located at the exit of horizontal curve
B5 - NCA,O, ON	Rail Crossing with No Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers ON.	Railroad Tracks intersect the roadway at an angle of 45 degrees
B6 - BA,O, OFF (BT)	Rail Crossing with Bus Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF (on approach). Bus Stops then moves forward, at this point, Flashers turn ON.	Bus Trick Scenario with two travel lanes per approach
T12 - TA,O,O OFF (TT)	Rail Crossing with Truck Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF on approach. Truck goes over crossing and flashers turn ON.	Truck Trick Scenario with two travel lanes per approach

In addition to the already previously discussed aspects of the trick scenarios, there are two other scenarios of interest due to their road geometry features- Scenario B3 and Scenario B5 and the compliance requirement at these scenarios. Scenario B3 shown in **Figure 17** takes place as the participant exits a horizontal curve; this scenario is important because although the advance warning sign and the flashers are visible, the radius of the curve limits the drivers' sight-distance and thus their ability to safely come to a stop for last-minute events.

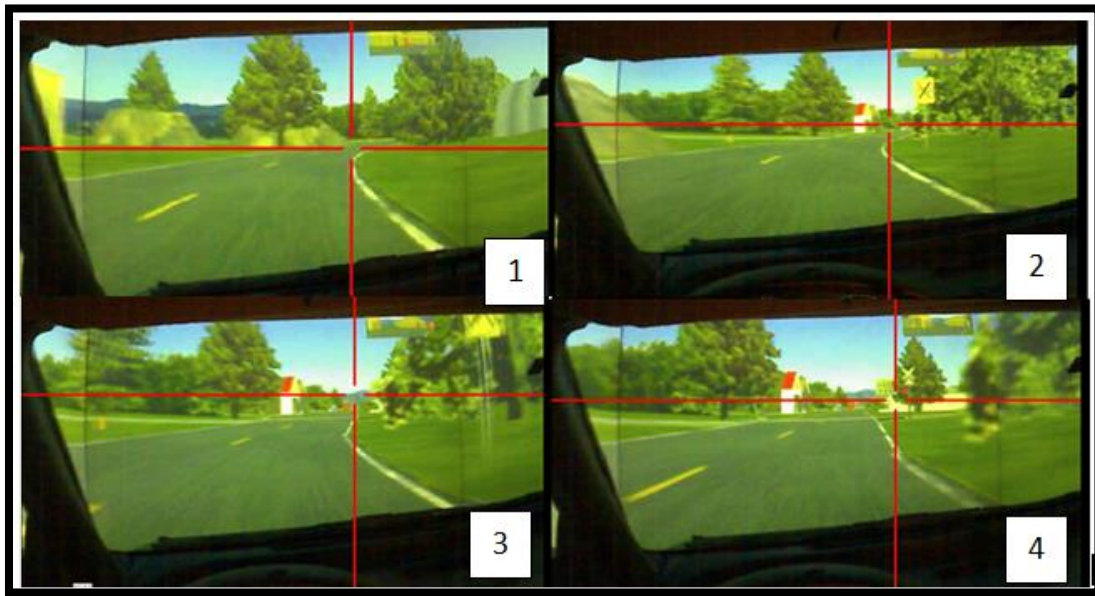


Figure 17: Drive Progression towards Scenario B3

Scenario B5, presents the driver with a grade crossing angled at 45 degrees. A drive progression for Scenario B5 is shown in **Figure 18** below. The combination of obscured traffic control devices, and an angled crossing can be deadly if the driver is not paying attention and does not realize that a train may emerge. Ironically, the angle at this crossing may also be a saving grace as the angle provides participants with the ability to glance further down the tracks and use this information to make a decision about their need to stop, in the event they fail to look at the flashing lights.

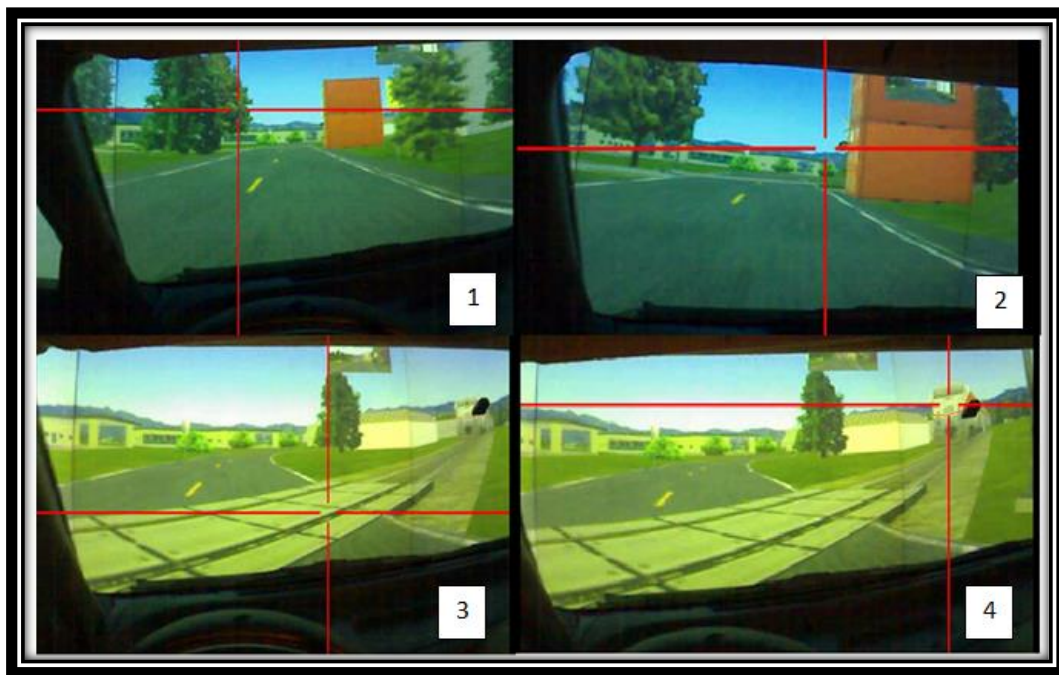


Figure 18: Drive Progression towards Scenario B5

3.1.8 Scenario Counterbalance

Participants were randomly assigned to three groups: control, in-vehicle, and cell phone conversation. Drive sequence was a within-participant factor. As previously described, if a control participant was assigned to begin with the Truck Drive, then they drove the Bus drive second (T_1, B_2) and if the next control participant was assigned to the Bus Drive first, then they saw the Truck drive second (T_2, B_1). Both the group assignment and the drive sequence controlled for sex of participants so that there were an even number of males and females in each group.

The Truck Drive scenarios complimented those of the Bus Drive. For example, in **Table 5** below; the second scenario of the Truck Drive features a car ahead, advance warning sign visible, flashing lights and crossbuck visible and lights ON (flashing). For the bus drive however, the participant then saw a car ahead, advance warning sign obscured, flashing lights obscured and flashing lights OFF (not flashing). Creating balance between the various aspects of visibility, presence of vehicle ahead, state of lights across scenarios and between drives was key in capturing true driver behavior as much as possible without creating a learning effect of what may happen next as they drove between crossings.

Table 5: Scenario Counterbalance

Truck (T)	$TnT_{stop}^{v,v,on}$	$1_{stop}^{v,v,on}$	$8_{Nstop}^{o,o,off}$	$3_{stop}^{o,o,on}$	$6_{Nstop}^{v,v,off}$	$TT_{stop}^{o,o,on}$
	<i>Truck Ahead</i>	<i>Car Ahead</i>		<i>Car Ahead</i>		<i>Truck Ahead</i>

			No Car Ahead		No Car Ahead	
Bus (B)	$BnT_{stop}^{v,v,off}$ <i>Bus Ahead</i>	$2_{Nstop}^{v,v,off}$ Car Ahead	$5_{stop}^{v,v,on}$ No Car Ahead	$4_{Nstop}^{o,o,off}$ Car Ahead	$7_{stop}^{o,o,on}$ No Car Ahead	$BT_{stop}^{o,o,off}$ <i>Bus Ahead</i>

Using the scenario counterbalance scheme described above, a sample counterbalance plan for six (6) participants is shown in **Figure 19** below. If a participant ended their participation in the study due to discomfort, then the assigned sequence was repeated on the next assigned participant.

		Scenario Sequence											
Subject ID		Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc 10	Sc 11	Sc 12
	Sub 1 Cell	TnT	1	8	3	6	TT	BnT	2	5	4	7	BT
	Sub 2 Cell	BnT	2	5	4	7	BT	TnT	1	8	3	6	TT
	Sub 3 In-vehicle	TnT	1	8	3	6	TT	BnT	2	5	4	7	BT
	Sub 4 In-vehicle	BnT	2	5	4	7	BT	TnT	1	8	3	6	TT
	Sub 5 Control	TnT	1	8	3	6	TT	BnT	2	5	4	7	BT
	Sub 6 Control	BnT	2	5	4	7	BT	TnT	1	8	3	6	TT

Figure 19: Sample Drive Counterbalance between Participants

3.1.9 Secondary Tasks: In Vehicle & Cell Phone

Participants were assigned to either engage or not engage in a secondary task. Those who were assigned to perform a secondary task were asked to either change the radio station or engage in a mock cell phone conversation. Performing a secondary task while driving has been shown to be detrimental to a drivers' ability to react to on-road situations (Samuel, 2014) (Horrey & Wickens, 2007)

3.1.9.1 In-Vehicle Task: Changing the Radio

Participants assigned to the in-vehicle task were prompted via on-screen instructions to change the radio station by using the car's dashboard radio. The prompts on the screen were automated to trigger at identified locations where the length of time to complete the task occupied most (if not all) of the participant's driving time between crossings. The goal was for the participant to encounter each crossing while still engaging with the radio. The use of pre-set station buttons was not allowed for this task. Participants had to use the "up" and "down" arrows to reach the target station.

3.1.9.2 Mock Cell Phone Task

Participants who were assigned to have a cell phone conversation were asked to listen to several sentences similar to those used by Baddeley (Baddeley, 1968). The Baddeley Reasoning Test is a 60-item test that is administered in 3 minutes and measures fluid intelligence through logical reasoning; this working memory task has proven useful in other studies (0). During this task, participants heard a 5-word sentence every 10 seconds and at the

conclusion of each sentence, the participant was then asked to identify the sentence's subject, object, and whether the sentence made logical sense. For example; when participants heard the sentence "Tracy ate the donut" they were expected to answer "Tracy – donut – yes". Similarly, they might have heard "Tracy sat on the cloud" and they were expected to respond "Tracy – cloud – no".

3.1.10 Dependent Variables & Hypotheses

In order to achieve the objectives of this dissertation, the following dependent variables were collected in order to test the experimental hypotheses.

3.1.10.1 Dependent Variables

The following dependent variables were collected at standard scenarios (glance behaviors) and scenarios of interest (glance and driver behavior):

- 1) Glance behaviors:
 - Did the driver glance towards the advance warning sign;
 - Did the driver glance towards flashing lights;
 - Did the driver glance to right and left sides of road from where train might be emerging?

2) Driver behaviors:

- Did the driver stop for scenarios where the lights were flashing;
- If no stop was required, did the driver visually slow down when the view was obscured?

3.1.10.2 Tests of Hypotheses

Both “Standard Scenarios” and “Trick Scenarios” were used to evaluate the following hypothesis:

General Hypothesis 1: I anticipate the greatest difference between drivers who are and those who are not distracted when both the flashing lights and the advance warning signs are obscured.

Standard Scenarios - Hypothesis 1: I anticipate the greatest difference between drivers who are and who are not distracted when both the flashing lights and the advance signs are obscured. A) If the driver does not need to come to a stop, then I am predicting that that distracted drivers will look less often at the flashers and the advance signs. B) If the driver does need to come to a stop, then I am predicting much the same thing with the proviso that all drivers will stop. Specifically, distracted drivers will look less often at the flashers and the advance signs, than drivers who are not distracted.

Standard Scenarios - Hypothesis 2: Here I am focusing just on the subset of distracted and undistracted drivers who have glanced at both the flashers and advance signs. I am predicting the same differences here between the vehicle and driver behaviors of the drivers who are and are not distracted as I predicted above. Since I am conditionalizing on both sets of drivers glancing at the signs, there will be no difference in their glance patterns to the flashers and warning signs.

Trick Scenarios Hypothesis: For the TnT (BnT) and TT (BT) scenarios, I am predicting for these scenarios that distracted drivers will glance less often at the flashers right before they enter the grade crossing than drivers who are not distracted. For the TT (BT) scenarios I will also collect compliance behaviors and am predicting that the distracted drivers will comply less of than the drivers who are not distracted.

3.2 Results

A total of fifty-three (53) participants were enrolled in experiment 1; 23 participants identified as females and 30 participants identified as males. There were forty-six participants used for the analysis. The average age for participants in experiment 1 was 28.2 years old ($SD = 7.0$) with an average driving experience of 10.57 years ($SD=7.32$). **Figure 20** below shows the randomized task assignment between groups.

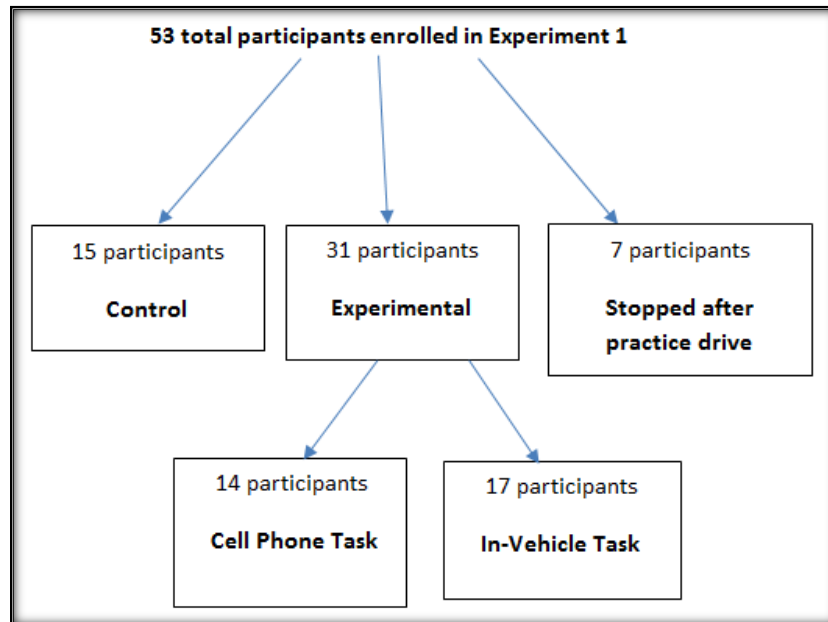


Figure 20: Experiment 1 – Participant Group Assignment

Fifty participants responded to the pre-study question of “In the past three months, have you text messaged while driving?” of which:

- 72% responded NO
- 28% responded YES

3.2.1 Data Collection and Analysis

There were forty-six participants with usable data files. Data was deemed not usable if there was equipment malfunction during the drive, or if the participant reported feeling discomfort (simulator sickness) during any portion of the study.

3.2.1.1 Eye Tracker Data

Eye tracker data was collected and scored by using a binary scoring scheme. The participant was given a score of 1, if a glance was detected and a score of 0, if the glance was not detected. There were 11 scoring areas per scenario where the participant was scored as taking a glance or not taking a glance; for a definition of each scored area, please see Error! Reference source not found. For ease of scoring and to facilitate visual inspection of data completeness, Bus drive scoring areas were assigned even numbers, and Truck Drive scoring areas were given odd numbers, however; the areas scored are exactly the same for both drives. A sample scoring sheet is shown in **Figure 21**. Participant drive sequence was noted by adding the number at the end of the participant's subject code. For example, the participant assigned to the code POTIL2, shown below drove the Truck drive first, as noted by the POTIL2-1 and the bus drive second, as noted by POTIL2-2.

			Bus											AoG = At Least One Glance												
														POTIL2-2											LC	
Sl. No	Abbreviation	Scenario Description																								
1	BA,V.OFF (BnT)	Rail Crossing with Bus Ahead, Advance Sign Visible, Flashers Visible, Flashers OFF	2	4	6	8	10	12	14	16	18	20	22													
2	CA,V.OFF	Rail Crossing with Car Ahead, Advance Sign Visible, Flashers Visible, Flashers OFF	1	1	0	0	1	1	1	1	1	1	1													
3	NCA,V.ON	Rail Crossing with No Car Ahead, Advance Sign Visible, Flashers Visible, Flashers ON	0	0	1	0	0	0	0	0																
4	CA,O.OFF	Rail Crossing with Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF	0	0	0	0	0	1	1	1																
5	NCA,O.ON	Rail Crossing with No Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers ON	0	0	0	0	0	0	0	1																
6	BA,O.OFF (BT)	Rail Crossing with Bus Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF	0	0	0	1	1	1	1	1	1	0	1	1												
Total			1	1	1	2	3	3	5	2	2	3	5	3												
Average			0.17	0.17	0.17	0.33	0.50	0.50	0.83	1.00	1.00	0.50	0.83	1.00												
Very focused on changing the radio																										
			Truck																							
Sl. No	Abbreviation	Scenario Description												POTIL2 - 1											LC	
7	TA,V.ON (TnT)	Rail Crossing with Truck Ahead, Advance Sign Visible, Flashers Visible, Flashers ON	1	3	5	7	9	11	13	15	17	19	21													
8	CA,V.ON	Rail Crossing with Car Ahead, Advance Sign Visible, Flashers Visible, Flashers ON	1	1	1	1	1	1	1	1	1	1	1													
9	NCA,O.OFF	Rail Crossing with No Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF	0	1	1	1	1	1	1	1	1	1	1													
10	CA,O.ON	Rail Crossing with Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers ON	0	0	0	1	1	1	1	1																
11	NCA,V.OFF	Rail Crossing with No Car Ahead, Advance Sign Visible, Flashers Visible, Flashers OFF	1	1	1	1	1	1	1	1																
12	TA,O.OFF (TT)	Rail Crossing with Truck Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF	0	0	0	1	1	1	1	1	1	1	1	1	1	1										
Total			2	3	3	6	6	6	6	2	2	5	4	1												
Average			0.33	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	0.83	0.67	1.00												

Figure 21: Sample Participant Eye Tracking Scoring Sheet

3.2.1.2 Compliance Data

There were four scenarios (B3, B5, B6, and T12) where participant's compliance (stop) behavior was scored. A binary scoring scheme was also used to score compliance behavior. The participant was scored as complying (score of 1) if the participant stopped at the crossing or if the researcher determined the participant slowed down to 5mph (this determination was made in real-time by consulting the vehicle parameter display available to the researcher while the drive was taking place). If the participant did not stop or slow down to 5mph, then they were scored as not complying and received a score of 0.

3.2.2 Test of Hypothesis: Results

One general hypothesis and three scenario specific hypotheses were tested for Experiment 1.

3.2.2.1 General Hypothesis

First, I conducted an overall statistical analysis, in order to determine the impact of the various levels of experimental factors on the proportion of glances to at least one of the lights at each scenario. I performed a logistic regression model within the framework of the Generalized Estimating Equations (GEE). I selected this model because my dependent variable – glances, was binary coded (0 or 1) and my data was binomially distributed.

The within-subject main effects (factors) in this experiment were: TCD visibility (Visible, Obscured), State of the Flashers (ON/OFF), and presence of Vehicle (Car Ahead, No Car Ahead). The between-subject main effect was group (control, radio, cell). Participants were included as a random main effect, in order to account for participant differences.

Using a backwards elimination process, I started with the highest order 4-way interaction, removed the non-statistical significant interactions at each level (3-way interactions) (2 – way interactions) and then looked at the statistical significant main-effects and interactions. The final model showed statistical significant main effects of: Car Presence [Wald $X^2=5.588$; $p=0.018$] and State of Flashers [Wald $X^2=44.144$; $p=0.001$]. The model did not show any main effects of Group [Wald $X^2=1.202$; $p=0.548$] and TCD visibility [Wald $X^2=1.702$; $p=0.192$]. The final model also included statistical significant interactions of: Group*Car Presence*TCD Visibility [Wald $X^2=6.532$; $p=0.038$] and Car Presence*Visibility*Flashers [Wald $X^2=30.425$; $p=0.001$].

With the knowledge of main effects and interactions produced by the model, first, it was hypothesized that the greatest difference in the proportion of glances to at least one of the lights would be seen between drivers who are and those who are not distracted when both the flashers and the advance warning signs are obscured. To evaluate this hypothesis, eye glance data for each grade crossing scenario was analyzed across all three groups. **Figure 22** below, shows the difference in the expected versus observed mean proportion of glances.

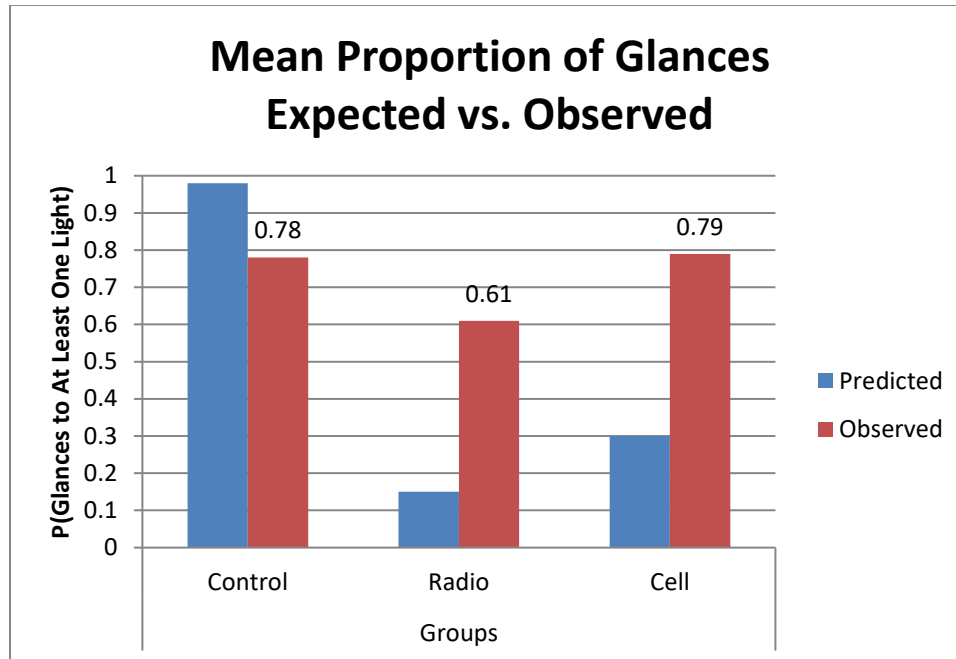


Figure 22: Experiment 1 Mean Proportion of Glances by Group

Since the initial model showed an interaction of Car Presence and TCD visibility, two separate analyses were conducted for the scenarios where a car was ahead and not ahead. An Univariate ANOVA within General Linear Model was used to determine whether differences in average glances were significant across scenarios where there was a car ahead and no car ahead between distracted and non-distracted drivers.

For car ahead scenarios, results in **Table 6** below showed there was a statistical significant interaction between having a car ahead and the TCD visibility for the mean proportion of glances to at least one of the lights $F(6,160) = 2.46, p = 0.027$. A simple main effects for distraction when a car ahead and TCD's were visible, showed a statistical significant difference in the mean number of glances towards at least one of the lights between drivers

who were distracted (performing radio task) than drivers who were not distracted $F(3,160) = 17.17, p = 0.001$.

In order to better understand whether the mean glance performance by group was significantly different across the scenarios where there was a car ahead, a post hoc pairwise comparison using a Bonferroni correction ($p = .001$) on the estimated means was performed. These results showed that in fact control (non-distracted) drivers did have a higher mean difference than distracted participants performing the radio task, for scenario NCA,O,OFF, .274 ($SE=.131$), but this result was not statistically significant ($p = .113$) thus this was not the case for cell phone participants. For the CA,O,ON scenario, the control participants had a slightly higher mean difference for the proportion of glances taken to at least one of the lights when compared to radio 0.130 ($SE = .131$) although this result showed no statistical significance ($p = .966$).

Table 6: Proportion of Glances to At Least One of the Lights When Car Ahead of Driver

No Trick	Car Presence	Visibility	Light State	CONTROL	RADIO	CELL
	CAR AHEAD	LIGHT VISIBLE	OFF	0.67	0.11	0.78
			ON	0.93	0.95	1
			% Diff	0.26	0.84	0.22
	CAR AHEAD	LIGHT OBSCURED	OFF	0.8	0.53	0.89
			ON	0.87	0.74	1
			% Diff	0.07	0.21	0.11

For no car ahead scenarios, an Univariate ANOVA within General Linear Model for main effects showed there was no statistical significant interaction between having no car ahead and the TCD visibility for the mean proportion of glances taken by groups to at least one of the lights $F(6,160) = 1.845, p = 0.094$.

A post-hoc pairwise comparison for scenarios with no car ahead and obscured TCD's showed that in non-distracted drivers did not show a higher mean difference in the proportion of glances taken to at least one of the lights than distracted participants for the NCA,O,OFF, although not statistical significant ($p > .05$) For the NCA,O,ON scenario, the control participants had a slightly higher mean difference for the proportion of glances taken to at least one of the lights when compared to radio 0.077 (SE = .153) and the cell phone .089 (SE = .186) though in both cases, results showed no statistical significance ($p > .05$).

The proportion of glances to at least one of the lights, in **Table 7** below, shows that when there was a car ahead of the driver, there was an effect of load for the radio participants, when the lights are obscured and off. It appears that this effect may be related more to the participant using the car ahead as a guide for when to adjust their behavior, and the state of the light (OFF) rather than the fact that the TCD is obscured. This is evidenced by the fact that when the lights are flashing (ON), the radio participant in this same car ahead, TCD obscured situation, glances more.

Table 7: Proportion of Glances to At Least One of the Lights When No Car Ahead of Driver

No Trick	Car Presence	Visibility	Light State	CONTROL	RADIO	CELL
	NO CAR AHEAD	LIGHT VISIBLE	OFF	0.73	0.58	0.56
			ON	0.93	0.58	0.89
			% Diff	0.20	0.00	0.33
	NO CAR AHEAD	LIGHT OBSCURED	OFF	0.13	0.42	0.44
			ON	0.87	0.79	0.78
			% Diff	0.73	0.37	0.33
		Difference Vis-Obs	% Diff	-0.53	-0.37	0.00

For no car ahead scenarios, although there was no statistical significant interaction between having a no car ahead and the TCD visibility for the mean proportion of glances taken by groups to at least one of the lights, the pairwise comparison showed that the distracted participants were glancing slightly higher than the control participants for the NCA, O,ON, scenario although as reported, not statistical significant. It appears than when there is no car ahead of the driver and the lights are obscured, the proper functionality of the lights becomes the saving grace for distracted participants. As shown in **Table 7**, participants increased the proportion of glances taken when the light was flashing (ON); this was particularly the case for control participants who although not distracted, when the light turned on showed a statistical significant increase in the proportion of glances taken to at least one of the lights ($p = .001$).

3.2.2.1.1 General Hypothesis Discussion

For the general hypothesis, I anticipated the greatest difference between drivers who are and those who are not distracted when both the flashers and the advance warning signs are obscured. The statistical tests showed that there is in fact an interaction between the presence and absence of a vehicle ahead of the driver and the visibility (obscured/visible) of the TCD's. For this analysis, only scenarios where the TCD's are obscured were considered.

3.2.2.2 Standard Scenarios Hypothesis 1

For standard scenarios where the driver does not need to come to a stop, it was expected that A) the distracted drivers would look less often at the flashers and the advance signs, than drivers who were not distracted. B) If the driver does need to come to a stop, then I am predicting much the same thing with the proviso that all drivers will stop. Specifically, it is expected that distracted drivers will look less often at the flashers.

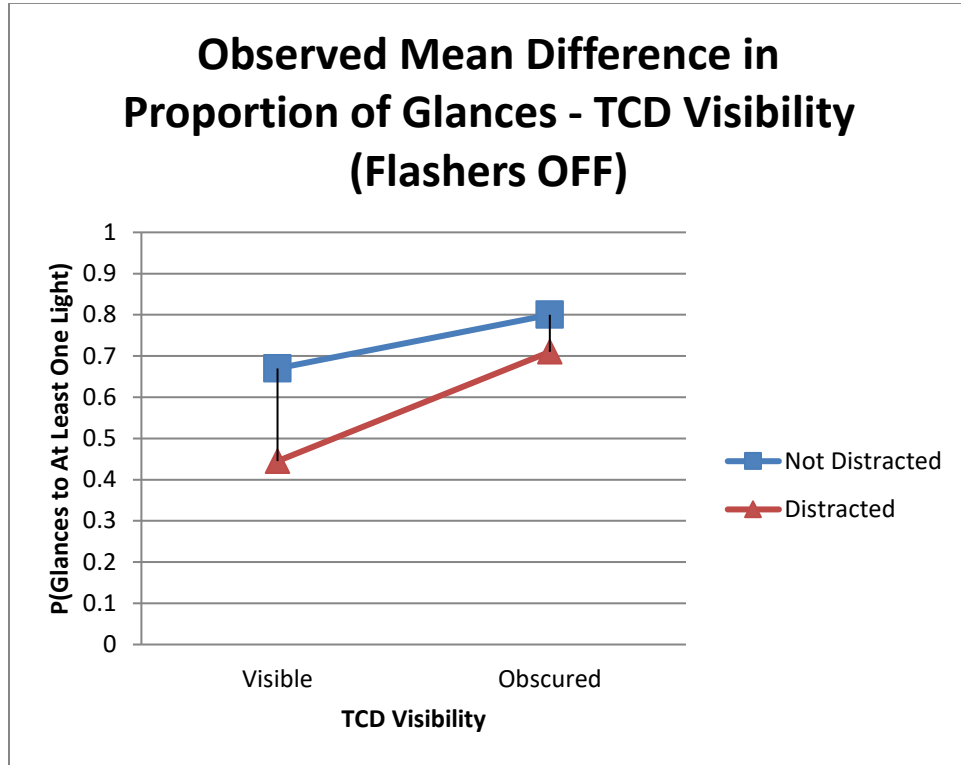


Figure 23: Proportion of Glances for Scenarios Where No Stop is Required

In order to evaluate **Part A** of this hypothesis, the subset of scenarios where the driver was not required to stop was analyzed:

- B2 - CA,V,OFF
- B4 - CA,O,OFF
- T9 - NCA,O,OFF
- T11 - NCA,V,OFF

Table 8: Summary of Means for Scenarios Where No Stop is Required

Scenarios	Control Mean	Control SD	Radio Mean	Radio SD	Cell Mean	Cell SD
B2 - CA,V,OFF	0.67	.49	0.11	.31	0.78	.44
B4 - CA,O,OFF	0.8	.41	0.53	.51	0.89	.33
T9 - NCA,O,OFF	0.13	.13	0.42	.51	0.44	.53
T11 - NCA,V,OFF	0.73	.73	0.58	.58	0.56	.53

A pairwise comparison using a Bonferroni adjustment showed the following results:

- Results for B2 - CA,V,OFF showed statistical significant results for the mean proportion of glances taken by the control group to at least one of the lights was .561 (95% CI (.245 to .877), $p = .001$ higher than the radio group. However, for this same scenario the mean proportion of glances taken by the control group was -.111(95% CI -.497 to .275) slightly less than the cell phone group, though this result showed no significance, $p = 1$.
- Results for B4 - CA,O,OFF showed that the control group should a mean difference of .274(95% CI -.042 to .590) higher than the radio group, though not statistical significant, $p = .113$. Similar to the previous scenario, when compared to the cell phone group, the mean difference between the control and the cell phone was -.089(95% CI -.475 to .297), less than the cell phone group, though not statistical significant $p = 1$.
- For the T9 - NCA, O, OFF scenario the mean difference in proportion of glances between the control group and the cell phone group was -.288(95% CI -.657 to .082) less, $p = .184$. A similar difference was found when comparing the control

group to the cell phone group. In this mean difference comparison, the mean proportion of glances taken by the control group was -.311(95% CI -.762 to .140) less, though the result has no statistical significance, $p = .291$.

- Lastly, for the T11 - NCA,V,OFF the results show that the mean difference in proportion of glances taken by the control group in this scenario was .154(95% CI -.215 to .524) higher than the mean proportion of glances taken by the radio group, although this result was not statistically significant. Similarly for the radio, results showed that the proportion of glances taken by the control participant was .178(95% CI -.273 to .629) higher than the cell phone group.

3.2.2.2.1 Standard Scenarios Hypothesis 1 Part A Discussion

The scenarios evaluated above are of extreme importance. Participants glancing in scenarios where no stop is required (no train present, no flashing lights) is really important because if the TCD's are doing what they are supposed to be doing (alerting the driver) then participant drivers should look even when the lights are not flashing. For scenario B2 - CA, V, OFF, results show a huge effect of load on the radio participants, causing them to look less. This is a huge problem, particularly because the lights are completely visible, yet the participant changing the radio almost never looks. It is possible that since there is a car ahead, they may use the car as a guide for what they should be doing "stopping/slowing down" when the car ahead performs those actions. When the lights are obscured in scenario B4 - CA,O,OFF the radio participants seem to be taking a higher proportion of glances even though the TCD's are

obscured. In this scenario, although there is a car ahead and the participant may still be using it as a guide, there may be something about the lack of “visibility” in the road ahead which encourages an increase in glance behavior.

The T9 - NCA,O,OFF scenario seems to have an impact across all groups, and in fact the control group looks less, though as previously stated, not statistically significant. However; this information may not give the whole picture, particularly for the control group. It is possible that since the control drivers are not distracted they are able to see down the road earlier on and thus determine that no glance is needed as they approach the obstruction. This is not completely safe behavior because in the case of grade crossings, lights turn on at the detection of a train and the lights turning on may catch the driver by surprise, creating a dangerous situation. It seems that in the case of the distracted drivers, the obscurity of the TCD’s coupled with no visual “hints” of a car ahead guiding them on when to look, may be causing the driver to become complacent that “nothing is happening” and thus they don’t look.

In order to evaluate **Part B** of this hypothesis, the subset of scenarios where the driver was required to stop was analyzed:

- B3 - NCA,V,ON
- B5 - NCA,O,ON
- T8 - CA,V,ON
- T10 - CA,O,ON

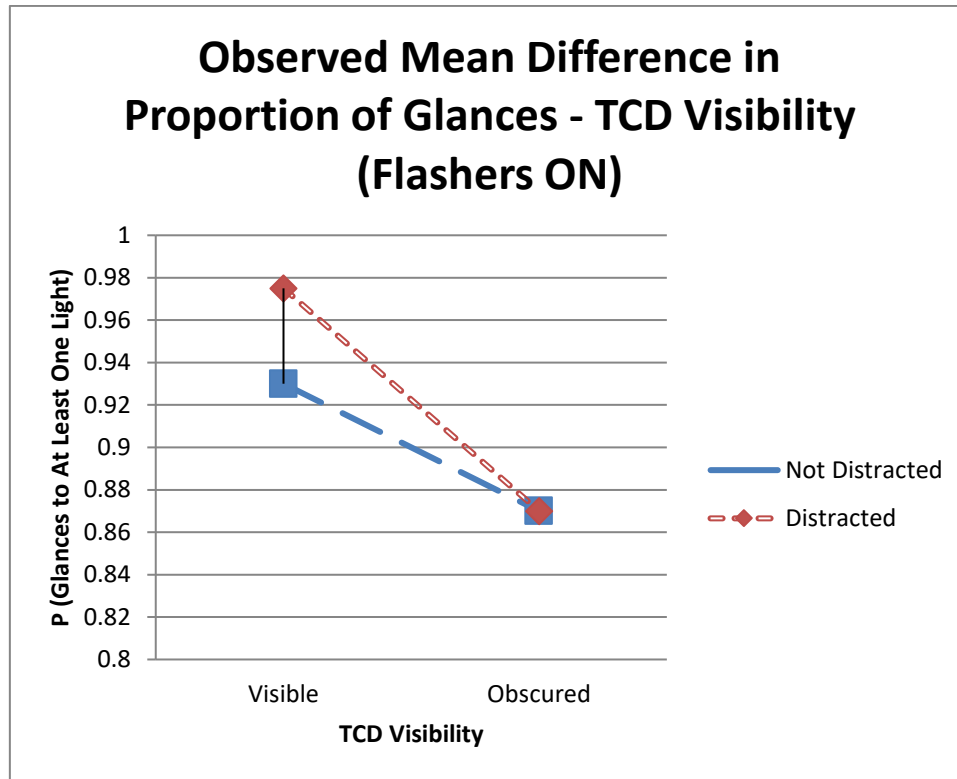


Figure 24: Proportion of Glances for Scenarios Where Stop is Required

Table 9: Summary of Glance Means for Scenarios Where Stop is Required

Scenario	Control Mean	Control SD	Radio Mean	Radio SD	Cell Mean	Cell SD
T8 - CA,V,ON	0.93	.26	0.95	.23	1	.00
T10 - CA,O,ON	0.87	.35	0.74	.45	0.89	.33
B5 - NCA,O,ON	0.87	.35	0.79	.42	0.78	.44
B3 - NCA,V,ON	0.93	.26	0.58	.51	0.89	.33

A post-hoc pairwise comparison with a Bonferroni adjustment showed the following results:

- For scenario B3 – NCA, V, ON the control group looked .354 (95% CI -.015 to .724), $p = .05$ higher than the radio group. For the cell phone group, the number of glances was slightly more by .044(95% CI -.015 to .724) glances, $p = 1$.
- For scenario B5 – NCA, O, ON, the control group is glancing at a slightly higher at .077(95% CI -.292 to .447) than the radio participants, and slightly higher when compared to the cell phone at .089(95% CI -.362-.540), $p = 1$ in both instances.
- For scenario T8 - CA, V,ON, the difference in the means showed that the control group looked -.014(95% CI -.330 to .302), $p = 1$ slightly less than the radio group. There was a similar difference when compared to the cell phone group, where the control group looked -0.67(95% CI -.453 to .319), $p = 1$ less than the control participants.
- For the T10 - CA,O,ON scenario, the control participants looked .130 (95% CI -.186 to .446) slightly higher than the radio group, but this result was not statistical significant, $p = .966$.

3.2.2.2.2 Standard Scenarios Hypothesis 1 Part B Discussion

The only significant result was for Scenario B3 – NCA, V, ON where the control group looked at a mean proportion of .354 (95% CI -.015 to .724), $p = .05$ glances higher than the radio

group. I think this result can be attributed to the lights being visible and flashing (ON) regardless of whether there was a car ahead since the mean proportion of glances taken by the control group for the CA,V, ON and the NCA, V, ON was exactly the same. In fact, as previously stated with general hypothesis 1, when a car is ahead, the radio group is more likely to glance and thus this becomes a key aspect for getting distracted drivers (particularly those performing an in-vehicle task such as changing the radio) to glance.

An unexpected outcome is that the mean proportion of glances taken by the radio group was higher when the lights were obscured and flashing (0.79) than when the lights were visible and flashing (0.58) and although this mean difference of .211(95% CI -.173 to .594) shows no significance ($p=1$), it may mean that since the driver is aware that they are performing a distracting task, they make just “look around” more and when they can’t see everything ahead of them (obscured by vegetation and such) they may feel the need to figure out what’s going on and as a result increase their glance behavior as they near the obstruction and see the lights that way.

In summary, it seems that the control group has an advantage when either a car is ahead and the lights are visible, even if off, and when there is no car ahead but the lights are visible and on. This points to the fact that if a driver is not distracted they may be encouraged to look at the light if visible because even though the light is off, “it’s there” so it is only natural that if there is a car ahead, a non-distracted driver preempts the behavior of the car ahead by taking glances.

On the other hand, if there is no car ahead, the driver may be look at the lights if it attracts its attention by flashing (turning ON). I believe that the distracted driver may be taking glances earlier on/ further back from the crossing and determine at that point that there isn't anything of interest ahead, unless of course, the lights turn on. Although the results above show that drivers are looking when a stop is required, (which is great) it does not provide conclusive information as to whether non-distracted drivers are really safer than distracted drivers by glancing more in these situations.

3.2.2.3 Standard Scenarios Hypothesis 2

Here, I am focusing just on the subset of distracted and undistracted drivers who have glanced at the flashers. I am predicting the same differences here between the vehicle and driver behaviors of the drivers who are and are not distracted as I predicted above. Since I am conditionalizing on both sets of drivers glancing at the flashers, there will be no difference in their glance patterns to the flashers and warning signs.

To test this hypothesis, I used the scenarios of interest B3, B5, B6, T12, since these were the scenarios where vehicle behavior was collected. Only the set of participants who were scored as looking were selected to then be analyzed for compliance behavior. I am testing whether the means of the samples are the same. As a reminder, participants were scored as complying (stopping) if they were to come to a complete stop, or a "creeping" speed of <5mph.

This speed determination was made in real-time by using the vehicle parameters controls monitored by the researcher during the experiments.

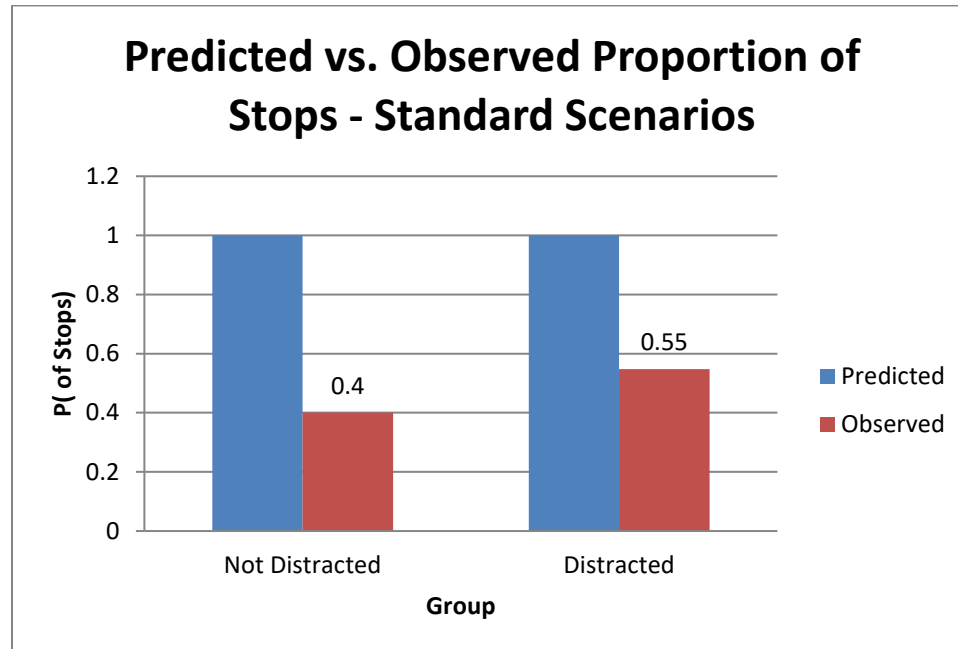


Figure 25: Predicted Vs. Observed Proportion of Stops Standard Scenarios

Control vs. Radio

An independent-samples t-test was used to determine if there were differences in compliance behavior for the sample group of distracted (In-vehicle task) and non-distracted drivers who glanced to at least one of the flashers. Homogeneity of variances was met, as assessed by Levene's test for equality of variances ($p=.361$). Control participants were slightly

more likely to stop for flashers than distracted participants on the, although not significant, .06, [95% CI -.13, to .25], $t(111) = .649$, $p = .517$.

Control vs. Cell Phone

The same procedure described above was followed for comparing the differences in compliance behavior for the sample group of participants in the control and cell phone group who glanced to at least one of the flashers.

On average, control participants were slightly more likely to stop for flashers than distracted participants performing a mock cell phone conversation. Results show a statistical significant difference in mean compliance behavior between the control group and cell phone group, with the control stopping on average 0.92 (95% CI, 0.71 to 1.15), $t(85) = 8.03$, $p = 0.001$ more frequently.

Radio vs. Cell Phone

Taking the analysis one step further, an independent t-test of distracted drivers showed that there was a statistical significant difference compliance behavior between the radio and the cell phone group, with the radio group stopping more than the cell phone group, 0.86 (95% CI, .641 to 1.09), $t(84) = 7.667$, $p = .001$.

3.2.2.3.1 Standard Scenarios Hypothesis 2 Discussion

An initial analysis of the proportion of drivers who stopped seems fairly close across all groups; however, it is very clear that although all these drivers are looking, their glances are not translating to high rates of compliance.

It becomes clear then, that a sweeping generalization cannot be made regarding the rate of compliance for non-distracted vs distracted drivers. It appears that although not distracted, the control group is not always stopping more, even when looking, particularly in situations where the lights are in fact turned on. In fact, the results above show that non-distracted drivers although looking in both conditions, also seem to have the same proportion of stops, whether the TCD's are obscured or visible. In comparison with distracted drivers on the cell phone though, it seems that the stops they do take are not taken by chance, as opposed to radio participants who when distracted, may stop for lights off of last-minute information.

Within distracted drivers, participants on the radio are stopping at a higher rate than cell phone participants, and on equal proportions to the control drivers. A second look at eye tracking tapes showed that radio participants although instructed to perform the task when the prompt was shown on the screen, did not always encounter crossings while performing the task. This means that at some point, either the participant reached the radio station faster than expected, or the situation the driver saw ahead became complex and they decided to stop the

task, thus by the time they encountered the crossing, they had essentially become “ non-distracted” drivers.

In summary, non-distracted drivers are not always stopping at higher rates than distracted drivers, but this may have to do more with comprehension of TCD’s at grade crossing than any other factor. In fact, for experiment 1, over half of my participants inquired about the proper action at grade crossings, and what the “flashing lights actually mean” during their debriefing session. Although comprehension was not tested for in this study, results from a survey on motorist understanding of selected warning signs showed that 66.5 percent of drivers misunderstood the meaning of the W10-1 Advance Warning Sign (Stokes et al., 1996). If comprehension is indeed an issue with TCD’s at grade crossings, then it becomes a challenge for a driver to properly react, even when not distracted. Driver compliance for trick scenarios – BT and TT will be discussed at a later point in the results section.

3.2.2.4 Trick Scenarios Hypothesis

For the Bus no Trick (BnT) and Bus Trick (BT) as well as for the Truck no Trick (TnT), Truck Trick (TT), I am predicting for these scenarios that distracted drivers will glance less often at the flashers right before they enter the grade crossing than drivers who are not distracted. For the TT (BT) scenarios I will also collect compliance behaviors and am predicting that the distracted drivers will comply less of than the drivers who are not distracted.

Glances Behavior

Scenarios used to test glances in this hypothesis:

- B1 - BA,V,OFF (BnT)
- B6 - BA,O,OFF (BT)
T7 - TA,V,ON (TnT)
- T12 - TA,O,OFF (TT)

An Univariate ANOVA within General Linear Model test was used to test for main effects between the presence of a large vehicle ahead, and the proportion of glances taken by drivers to at least one of the lights.

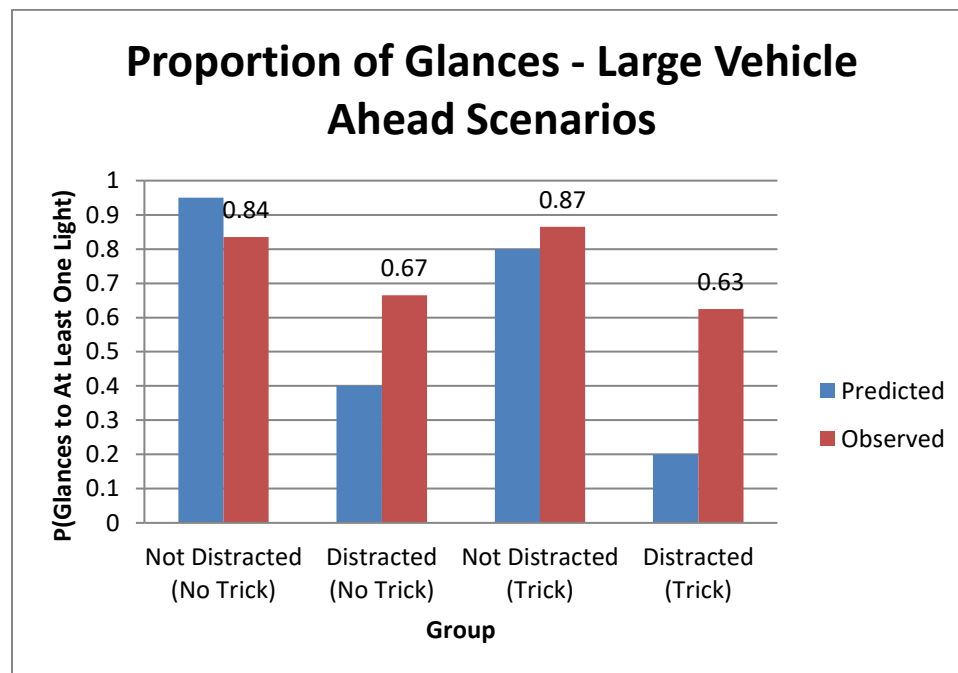


Figure 26: Proportion of Glances – Large Vehicle Ahead Scenarios

There was a significant interaction between the presence of a large vehicle ahead, and the proportion of glances taken by drivers to at least one of the lights, $F(6,120) = 5.89$, $P < .005$. Knowing that a large vehicle ahead has a significant impact on glances, a post-hoc test of simple main effects analysis was analyzed to see whether main effects existed based on the conditions of each scenario and the mean proportion of glances to at least one of the lights by each individual group.

The post-hoc analysis showed:

- A significant difference in glances between groups for the BnT scenario, $F(2, 40) = 6.466$, $p = .004$.
- Post-hoc tests showed that the proportion of glances to at least one of the lights was significantly larger for the Radio group $.054(SE = 0.16)$, $p = .006$ in the BnT scenario.
- There was a statistical significant difference in glances between groups for the BT scenario, $F(2, 40) = 3.469$, $p = .041$.
- Post-hoc tests showed that the proportion of glances to at least one of the lights was significant for the Radio group $0.32(SE = 0.12)$, $p = .04$ in the BT scenario.
- There was no difference in glances between groups for the TnT scenario, $F(2, 40) = .746$, $p = .481$.
- There was a no significant difference in glances between groups for the TT scenario, $F(2, 40) = 1.171$, $p = .321$.

Table 10: No Trick/Trick Scenario Proportion of Glances

Scenario	Control Glance	Radio Glance	Cell Glance
B1 - BA,V,OFF (BnT)	0.8	0.26	0.67
B6 - BA,O,OFF (BT)	1	0.68	0.89
T7 - TA,V,ON (TnT)	0.87	0.84	1
T12 - TA,O,OFF (TT)	0.73	0.89	0.67

3.2.2.4.1 Trick Scenarios Hypothesis Glances Discussion

Results show that the radio group looked more on average than the control though this was not statistical significant ($p = .496$). Glances to the lights were scored after the large vehicle ahead had moved forward. For the BnT scenario, it seems that there was an effect of load for the radio participants. It is possible that the participants, since distracted due to performing a task, assumed that it was safe for them to cross, when the bus in front had moved. In the case of the control group, which was not distracted, and the cell phone participants who didn't have to take the glances away from the forward roadway, these participants were showed a higher proportion of glances, once the bus moved forward.

The Bus Trick scenario, B6 - BA,O,OFF (BT) showed a significant difference for the proportion of glances taken by the radio group. While it seems that all three groups did fine for this scenario, the radio group was probably still engaged in changing the radio station, and as a result looked less. Again, participants in this group were probably using the bus moving forward, as an indicator that it was safe for them to do so. In the case of the control, and the cell phone participants, since their gaze was straight ahead, they were probably looking more.

The Truck no Trick Scenario, T7 - TA,V,ON (TnT) showed a pretty high number of glances to at least one of the lights after the truck had moved forward. This may be due to the fact that the truck stopped for flashing lights, and as a result the participant stopped behind the truck. Whether distracted or not, it is expected that if one sees flashing lights it will attract your eyes to the location where those lights are. My observation was that even after the truck moved forward, participants looked more, perhaps as a form of confirming that the lights were indeed off.

The Truck Trick Scenario, T12 - TA,O,OFF (TT) showed a slight decrease in the proportion of glances taken by participants, though not statistically significant $p > 0.05$. On approach to the crossing, participants were behind the truck, and as a result the truck obscured the right flasher but not the left flasher on the opposing approach. In fact, a visual inspection of the eye tracking scoring spreadsheet showed that the participants frequently consulted the light on the left to obtain information. It is possible that since the truck did not stop at the crossing as it did during the TnT scenario, participants adjusted their glance pattern slightly. In the case of the radio participants, as previously discussed, eye tracking videos showed that it was common for

participants to “let go” of the task perhaps when either not feeling completely comfortable engaging with the radio, or because they had already completed the task, hence attributing this behavior to looking more. It is also possible that as a result of the element of surprise, participants experienced when the truck stopped abruptly during the first scenario. In the case of cell phone participants, if their gaze was on the truck, then it is probable that some of the participants used the truck as a guide for proper behavior.

Compliance Behavior

Compliance behavior was only scored for Bus Trick and Trick Scenarios since in the No Trick scenarios, the participant had to stop due to the vehicle in front coming to a complete stop. An independent samples t-test was used to determine how each group complied (stopped) with the trick scenarios.

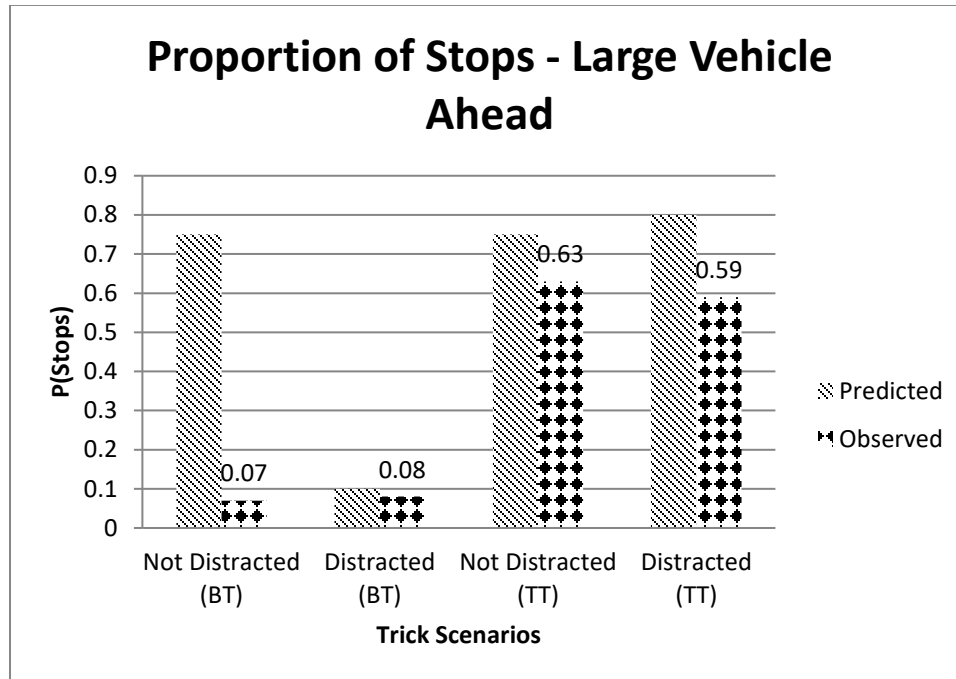


Figure 27: Proportion of Stops – Large Vehicle Ahead

Results for the t-test show:

There was a statistical significant difference in compliance behavior between the control group and the cell phone group $t(24) = .220$ $p=.024$, although there was no statistical significant difference between the control group and the radio group, as well as no statistical significant difference between the radio and the cell phone group.

Table 11: Proportion of Drivers in Compliance for Trick Scenarios

Scenario	Control Yield %	Radio Yield %	Cell Yield %
B6 - BA,O,OFF (BT)	0.07	0.07	0.09
T12 - TA,O,OFF (TT)	0.63	0.63	0.55

3.2.2.4.2 Trick Scenarios Hypothesis Compliance Discussion

It is important to discuss the Bus Trick Scenario B6 - BA, O,OFF since with the exception of a few drivers, no one stopped. Although a search in the literature did not reveal any relevant information on bus perception, it is a popularly known fact that drivers dislike buses. Regardless of what the driver knows about their driving environment, the presence of a bus ahead usually means slow moving vehicle, and buses are also associated with frequent stops. It is not uncommon to witness drivers going around the bus, when passengers are alighting at a bus stop.

In addition to this perception, in my study, participants witnessed a bus stopping “just because” during scenario Bus no Trick. I say “just because” since upon visual inspection, the driver didn’t seem to find a reason why the bus must have stopped. Unless the driver is aware that buses come to complete stops at grade crossings, then they may have attempted to go around the bus on the adjacent travel lane. In fact, this was the case for a handful of participants

in experiment 1. During the practice portion of the study, participants were told to always remain on the rightmost lane. It was not uncommon for the researcher to remind the participant to stay on the right lane after witnessing the participant pull to the adjacent left lane during the first scenario. But not at any other point during the simulation.

When participants see the bus again during the last scenario, the natural inclination is to associate the bus with slow moving vehicle ahead, and thus drivers are more willing to pass the bus on the left lane without making an attempt to stop at the crossing. Although, as previously stated drivers are looking during this scenario, it does not translate to higher stopping behavior.

Although the control and the radio groups had the same rate of compliance for the bus drive, the results show that in fact those compliant events for the radio group may be caused by chance.

3.3 Summary

Experiment 1 served as basis for evaluating the current state of traffic control devices under driver distraction. While in some instances the control group fared much better than the distracted group, there is still some variation as to what the safest conditions may be for ensuring that drivers not only look, but stop when needed.

It is clear that distracted drivers have a harder time detecting grade crossings accordingly, particularly for those performing an in-vehicle task. However, there are other driver characteristics such as comprehension, which may get in the way of proper driver behavior on approach of a grade crossing.

The second experiment in this study aims to enhance grade crossing visibility and hopefully provide another layer of alertness for distracted drivers and non-distracted drivers alike.

CHAPTER 4

EXPERIMENT 2: A SIMULATOR EVALUATION OF DYNAMIC ENVELOPE PAVEMENT MARKINGS

4.1 Methodology

Results from Experiment 1 made it very clear that all groups of participants needed as much help as possible with staying safe on the roadway, particularly when performing a distracting task. Given the high cost of enhancing grade crossings with gates, it was of utmost importance to evaluate a treatment which could be cost effective, and easy to maintain. With this in mind, the dynamic envelope markings (described in a latter section) were selected as the supplemental treatment for evaluation during this second driving simulator experiment.

4.1.1 Participants

There were 46 participants enrolled in experiment 2; 24 participants identified as female and 22 participants identified as male. The average age for this group was 23.6 years old (SD = 5.59) with an average number of driving experience of 6.9 years (SD = 5.82). The minimum required age for participation in this study was 19 years, participants were required to be in possession of a valid driver's U.S license. As with experiment 1, participants were recruited using advertisement material previously approved by the Institutional Review Board (IRB) at the University of Massachusetts Amherst. Forty-one (41) percent of drivers self-reported driving more than 10,001 miles in the past 12 months.

4.1.2 Experimental Procedure

The experimental procedure was exactly the same as for experiment 1. Please refer to Section 3.1.2.

4.1.3 Driving Simulator

As in experiment 1, the RTI, Inc. was also used for evaluating the scenarios in this experiment. Please refer to Section 3.1.3.

4.1.4 ASL Eye Tracker

The eye tracker was also used for experiment 2. Please refer to Section 3.1.4.

4.1.5 Traffic Control Devices for Evaluation

In addition to the warning sign and the crossbuck, scenarios in experiment 2 were supplemented with dynamic envelope pavement markings. The dynamic envelope markings are painted in the “dynamic envelope” of the region between and immediately adjacent to the tracks at a grade crossing.



Figure 28: Dynamic Envelope Markings (U.S. DOT)

The goal of the added markings and signage is to positively influence driver behavior by reducing the number of vehicles which come to a stop within the dynamic envelope, thus reducing the possibility that a vehicle is present on the tracks when a train approaches (Gabree et al., 2014). The dynamic envelope pavement markings are currently included in the latest version of the MUTCD.

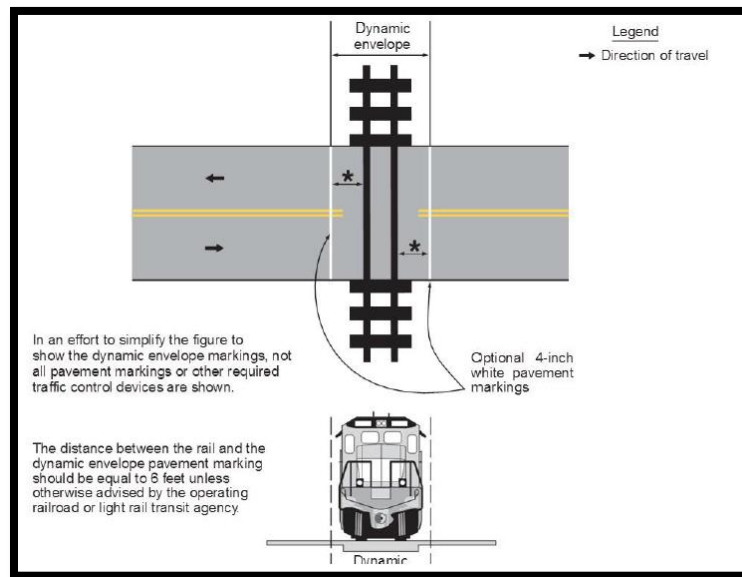


Figure 29: MUTCD depiction of Dynamic Envelope (MUTCD 8B-8)

Researchers from the U.S. John A. Volpe Transportation Systems Center performed a before-treatment and post-treatment naturalistic evaluation on a set of multi-lane, gated, grade crossings in the State of Florida where the markings had been painted. Over two hundred hours and 12,000 vehicles were coded for safe stopping behavior. Results showed a positive effect on driver stopping behavior at the grade crossings after the addition of the markings. Most importantly, the addition of these markings decreased the number of violations (drivers going through descending and around horizontal gates). In addition, the introduction of these markings may have increased awareness of the crossing, and as a result drivers became more cautious.

The success of these markings in combination with gates, make me hopeful that this same benefit could be reaped at non-gated active grade crossings. Specifically, under conditions

of driver distraction. With this in mind, the markings shown in **Figure 30** below were introduced into the RTI, Inc., simulator environment for evaluation.

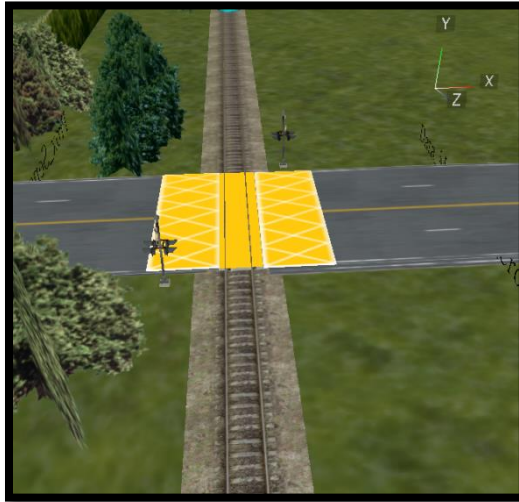


Figure 30: Top View of Dynamic Envelope Pavement Markings in RTI, Inc., Simulator

4.1.6 Simulator Drives

The same simulator drives in experiment 1 were used for experiment 2. Please refer to Section 3.1.6.

4.1.7 Scenario Design & Description

As previously mentioned, the same scenarios used in experiment 1 were also used for experiment 2, with the addition of the markings. The markings were designed using Paintshop

Pro® and then imported into the simulator software. Markings were placed to scale, following MUTCD guidelines.

While the scenarios are exactly identical, it is important to revisit the scenarios of interest and the potential for enhanced visibility at these scenarios as a result of the addition of markings. What distinguishes these four key scenarios, in addition to the driver's glance behavior, yield/stopping behavior was also scored at these crossings. **Table 12** describes the four scenarios as well their features of interest.

Table 12: Revisiting Scenarios of Interest

Scenario of Interest	Scenario Description	Road Geometry Feature
B3 - NCA,V, ON	Rail Crossing with No Car Ahead, Advance Sign Visible, Flashers Visible, Flashers ON	Crossing located at the exit of horizontal curve
B5 - NCA,O, ON	Rail Crossing with No Car Ahead, Advance Sign Obscured, Flashers Obscured, Flashers ON.	Railroad Tracks intersect the roadway at an angle of 45 degrees

B6 - BA,O, OFF (BT)	Rail Crossing with Bus Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF (on approach). Bus Stops then moves forward, at this point, Flashers turn ON.	Bus Trick Scenario with two travel lanes per approach
T12 - TA,O,O OFF (TT)	Rail Crossing with Truck Ahead, Advance Sign Obscured, Flashers Obscured, Flashers OFF on approach. Truck goes over crossing and flashers turn ON.	Truck Trick Scenario with two travel lanes per approach

One of the immediate benefits of adding these markings is the visibility provided to the crossing/road surface. In the upper left image of **Figure 31**, as a participant begins to enter scenario B3 which is located at the exit of a horizontal curve, the markings immediately become visible, (as pointed by the yellow arrow) before the participant even began to enter the curve.

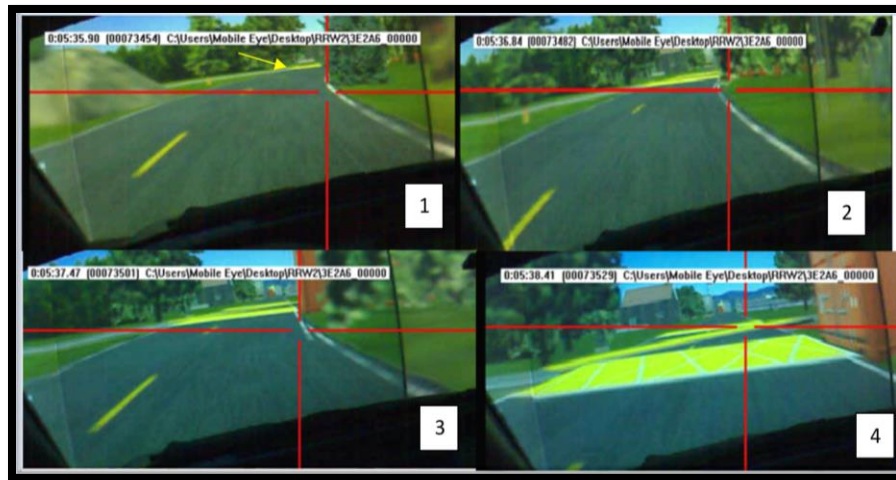


Figure 31: Scenario B3 Reveal

The same visibility effect is seen for Scenario B6 (**Figure 32**) where the tracks intersect the roadway at an angle of 45 degrees. As the participant begins to approach this crossing (number 1), it becomes clear that something ahead looks different (as noted by the yellow arrow). As the participant gets closer to the crossing, the markings provide enhanced visibility.

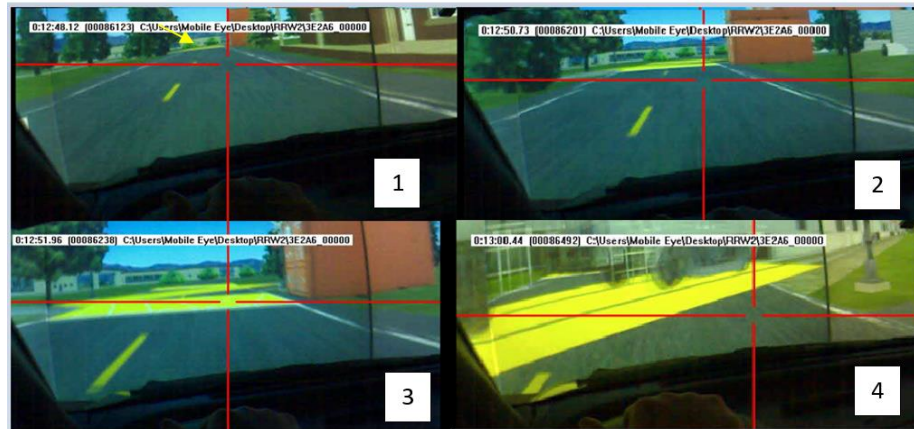


Figure 32: Scenario B6 Reveal

Finally, for the Bus Trick (B6) in **Figure 33** and Truck Trick (T12) in **Figure 34** scenarios shown below, the addition of the markings enhances the visibility of the crossing, even when a large vehicle is ahead.

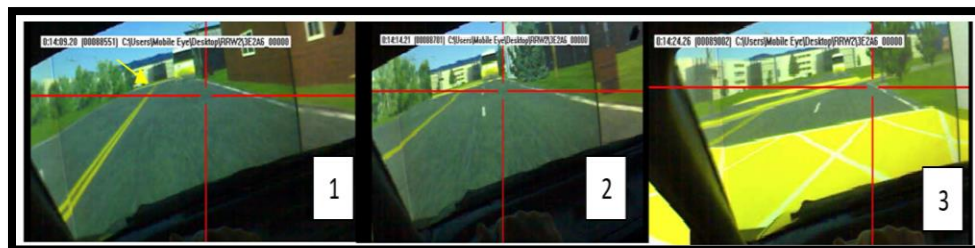


Figure 33: B6 – Bus Trick Scenario Reveal

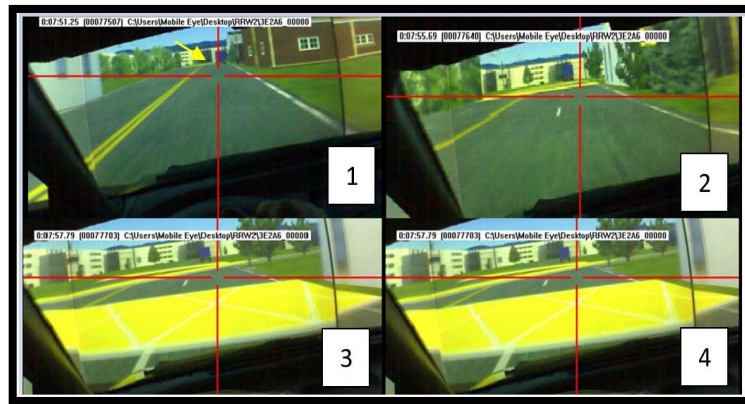


Figure 34: T12 – Truck Trick Scenario Reveal

4.1.8 Scenario Counterbalance

The same counterbalance scheme used in experiment 1, was used for experiment 2.

Please see Section 3.1.8.

4.1.9 Secondary Tasks

As with the first experiment, participants were randomly assigned to three groups: control, distracted (in-vehicle task), and performing a mock cell phone conversation. Please refer to Section 3.1.9 for further discussion.

4.1.10 Dependent Variables & Hypotheses

4.1.10.1 Dependent Variables

In order to evaluate my hypotheses, the following dependent variables were collected at standard scenarios (glance behaviors) and scenarios of interest (glance and driver behavior):

1) Glance behaviors:

- Did the driver glance towards the advance warning sign;
- Did the driver glance towards flashing lights;
- Did the driver glance to right and left sides of road from where train might be emerging and.

2) Driver behaviors:

- Did the driver stop for scenarios where the lights were flashing;
- If no stop was required, did the driver visually slow down when the view was obscured?

4.1.10.2 Hypotheses

Much the same hypotheses will be evaluated in experiment 2 as were evaluated in experiment 1, except that now, one wants to know whether the supplemental treatment reduces the effects of distraction. Both “Standard Scenarios” and “Trick Scenarios” were used to evaluate the following hypothesis:

General Hypothesis 1: I anticipate the greatest difference between drivers who are and those who are not distracted when both the flashing lights and the advance warning signs are obscured.

Standard Scenarios Hypothesis 1: For standard scenarios where the driver does not need to come to a stop, it was expected that the distracted drivers would look less often at the flashers and the advance signs, than drivers who were not distracted. I also anticipated an increase in driver compliance behavior for crossings with the supplemental treatment, than the standard treatment. If the driver does need to come to a stop, then much the same behavior is expected with the proviso that all drivers will stop. Specifically, distracted drivers will look less often at the flashers and the advance warning sign, and will slow down closer to the grade crossing than drivers who are not distracted. Here, I am also expecting that the differences will be greater in crossings with the standard treatment than crossings with the supplemental treatment.

Standard Scenarios Hypothesis 2: Here I am focusing just on the subset of distracted and undistracted drivers who have glanced at the flashers. I am predicting the same differences here between driver behaviors of the drivers who are and are not distracted as I predicted above. Since I am conditionalizing on both sets of drivers glancing at the flashers, there will be no difference in their glance patterns to the flashers and warning signs. I am also expecting that the differences will be greater in crossings with the standard treatment than crossings with the supplemental treatment.

Trick Scenarios Hypothesis: For the Truck Trick (TT) and Bus Trick (BT) scenarios, it is predicted that distracted drivers will glance less often at the flashing lights right before they enter the grade crossing than drivers who are not distracted. For the TT and BT scenarios, it is predicted that the distracted drivers will comply (stop) less than the drivers who are not distracted. I am predicting that among drivers who glance, the effects of distraction will be smaller in the supplemental treatment than they will be in the standard treatment.

4.2 Results

There were 46 participants enrolled in experiment 2; 24 participants identified as female and 22 participants identified as male. Data for 44 participants was used for this analysis. The average age for this group was 23.6 years old ($SD = 5.59$) with an average number of driving experience of 6.9 years ($SD = 5.82$). The minimum required age for participation in this study was 19 years; participants were required to be in possession of a valid driver's U.S license.

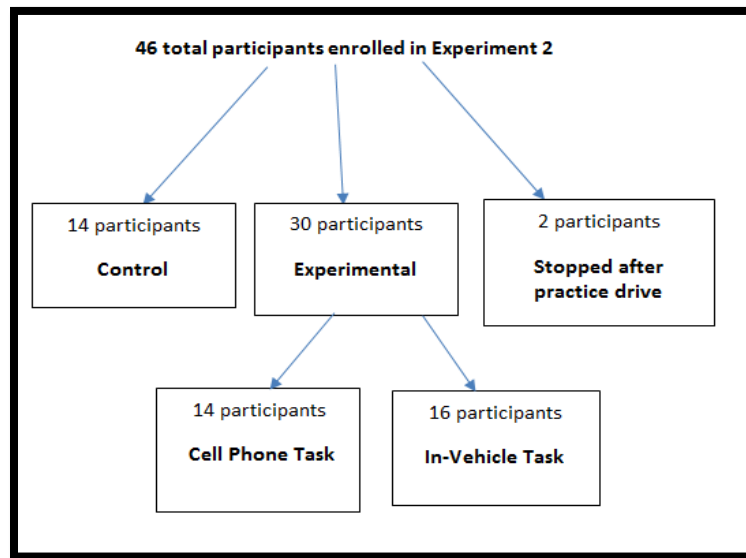


Figure 35: Experiment 2– Participant Group Assignment

Forty-four participants responded to the pre-study question of “In the past three months, have you text messaged while driving?” of which:

- 63.6% (28) responded NO
- 36.4% (16) responded YES

4.2.1 Data Collection & Analysis

A data collection procedure was exactly the same as the data collection for experiment

1. Reference Section 3.2.1

4.2.1.1 Eye Tracker Data

Eye tracker data was scored exactly the same for experiment 2 as for experiment 1.

Reference Section 3.2.1.1.

4.2.1.2 Compliance Behavior

Compliance behavior was also scored as previously described in experiment 1.

Reference Section 3.2.1.2.

4.2.2 Testing of Hypothesis: Results

4.2.2.1 General Hypothesis 1

As with experiment 1, I first conducted an overall statistical analysis, in order to determine the impact of the various levels of experimental factors on the proportion of glances to at least one of the lights at each scenario. I performed a logistic regression model within the framework of the Generalized Estimating Equations (GEE). I selected this model because my dependent variable – glances, was binary coded (0 or 1) and my data was binomially distributed.

The within-subject main effects (factors) in this experiment were: TCD visibility (Visible, Obscured), State of the Flashers (ON/OFF), and presence of Vehicle (Car Ahead, No Car Ahead). The between-subject main effect was group (control, radio, cell). Participants were included as a random main effect, in order to account for participant differences.

Using a backwards elimination process, I started with the highest order, a 4-way interaction, removed the interactions with no statistical significance at each level (3-way

interactions) (2 – way interactions) and then looked at the statistical significant main-effects and interactions. The final model showed statistical significant main effects of: State of Flashers [Wald $X^2=26.966$; $p=0.001$]. The model did not show any main effects of Group [Wald $X^2=8.792$; $p=0.210$], Car Presence [Wald $X^2=3.539$; $p=0.061$], and TCD visibility [Wald $X^2=2.010$; $p=0.156$]. The final model also included significant interactions of: Car Presence*TCD Visibility [Wald $X^2=13.694$; $p=0.003$] and Car Presence*Visibility*Flashers [Wald $X^2=11.972$; $p=0.007$].

Given the results of the model, I anticipate the greatest difference between drivers who are and those who are not distracted when both the flashing lights and the advance warning signs are obscured.

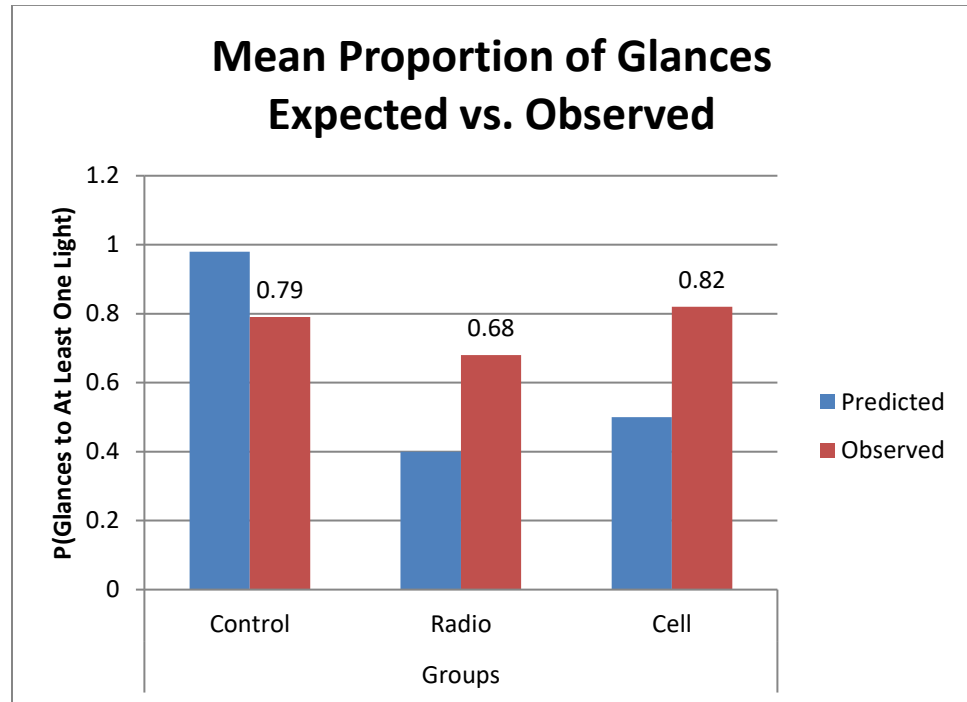


Figure 36: Experiment 2 - Mean Proportion of Glances Expected vs Observed

To test this hypothesis, the following scenarios were selected:

- B4 - CA,O,OFF,
- B5 - NCA,O,ON,
- T9 - NCA,O,OFF
- T10 - CA,O,ON.

Car Ahead

Let's first look at the two scenarios with a car ahead of the driver. An Univariate within General Linear Model test showed no significant interaction between groups and the scenarios

when there was a car ahead, on the proportion of glances taken to at least one of the lights when the markings are present $F(6, 26.758) = .531, p = .784$.

Table 13: Proportion of Glances to At Least One Light for Car Ahead Scenarios

No Trick	Car Presence	Visibility	Light State	CONTROL	RADIO	CELL
	CAR AHEAD	LIGHT VISIBLE	OFF	0.64	0.38	0.69
			ON	0.79	0.85	0.92
			% Diff	0.15	0.46	0.23
	CAR AHEAD	LIGHT OBSCURED	OFF	0.71	0.62	0.85
			ON	0.86	0.85	0.85
			% Diff	0.15	0.54	0.00
			Difference Vis-Obs	0.00	0.24	0.23

Although there are no main effects, is important to comment on the proportion of glances taken by the three groups for scenarios when the TCD's are obscured. In general, it seems that when a car is ahead of the driver, and the lights are obscured and not flashing (OFF) participants in all conditions are looking at a fairly high rate, thus there is very little effect of load shown by the distracted drivers. For the scenario with car ahead, lights obscured and flashing (ON) all participants increased the proportion of glances taken to at least one of the lights. These initial results show that when the lights are ON, even if obscured, they are attracting the driver's attention. Let's now consider the set of scenarios when there's no car ahead.

No Car Ahead

As with the Car Ahead Scenarios, there was no statistical significant interaction no between groups and the various scenarios when there was no car ahead, for the proportion of glances taken to at least one of the lights when the markings are present, $F(6, 148) = .316, p = .928$.

Table 14: Proportion of Glances to At Least One Light for No Car Ahead Scenarios

No Trick	Car Presence	Visibility	Light State	CONTROL	RADIO	CELL
	NO CAR AHEAD	LIGHT	OFF	0.86	0.69	0.77
		VISIBLE	ON	0.93	0.69	0.92
			% Diff	0.07	0.00	0.15
	NO CAR AHEAD	LIGHT	OFF	0.36	0.23	0.46
		OBSCURED	ON	0.79	0.77	0.92
			% Diff	0.43	0.54	0.46
		Difference Vis-Obs	% Diff	-0.36	-0.54	-0.31

A look at **Table 14** above, shows that the proportion of glances to at least one of the lights for the no car ahead, TCD's obscured and OFF when markings are present, is significantly less than when there is no car ahead, lights are obscured and ON. It appears that although there is an effect of load for distracted drivers, the control participants are also not glancing much. One possible reason for this low proportion of glances is that the combination of not having a car ahead when the lights are obscured and OFF creates a complacent driver, even when not distracted and they get lazy about looking for potential dangers on the road ahead. In addition,

the markings may be alerting the driver earlier on of the presence of the crossing, thus the driver may look from further back and not have to look at they get closer.

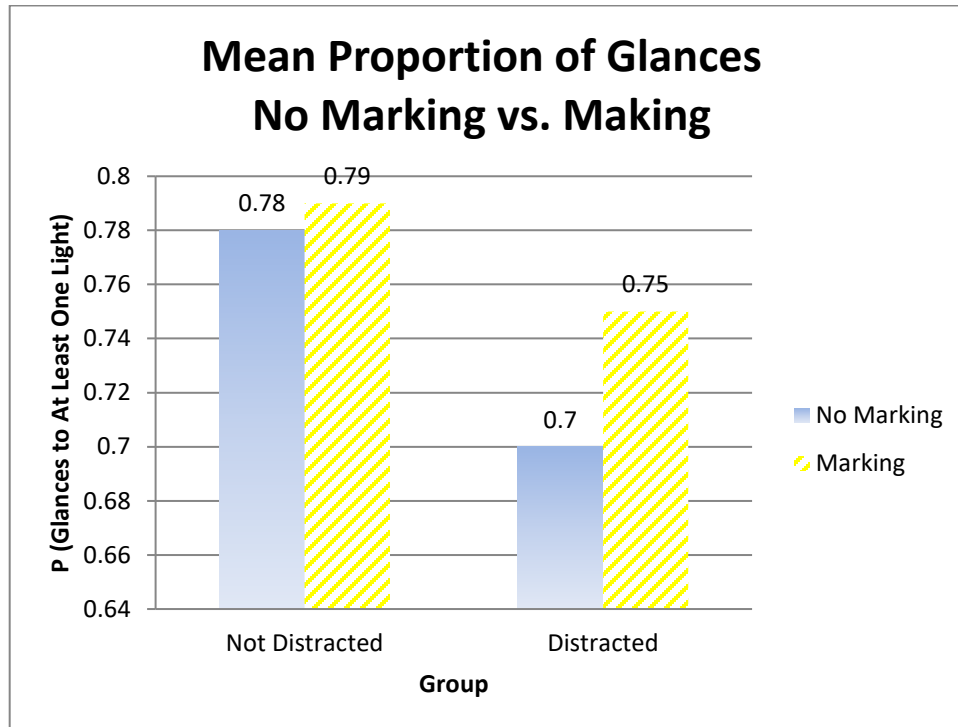


Figure 37: Mean Proportion of Glances No Marking vs. Marking

4.2.2.2 Standard Scenarios Hypothesis 1

Standard Scenarios Hypothesis 1: For standard scenarios a) where the driver does not need to come to a stop, it was expected that the distracted drivers would look less often at the flashers and the advance signs, than drivers who were not distracted b) If the driver does need to come to a stop, then much the same behavior is expected with the proviso that all drivers will

stop. Specifically, distracted drivers will look less often at the flashers and the advance warning sign, than drivers who are not distracted. Here, I am also expecting that c) the differences will be greater in crossings with the standard treatment than crossings with the supplemental treatment.

a) Scenarios where driver does not need to stop

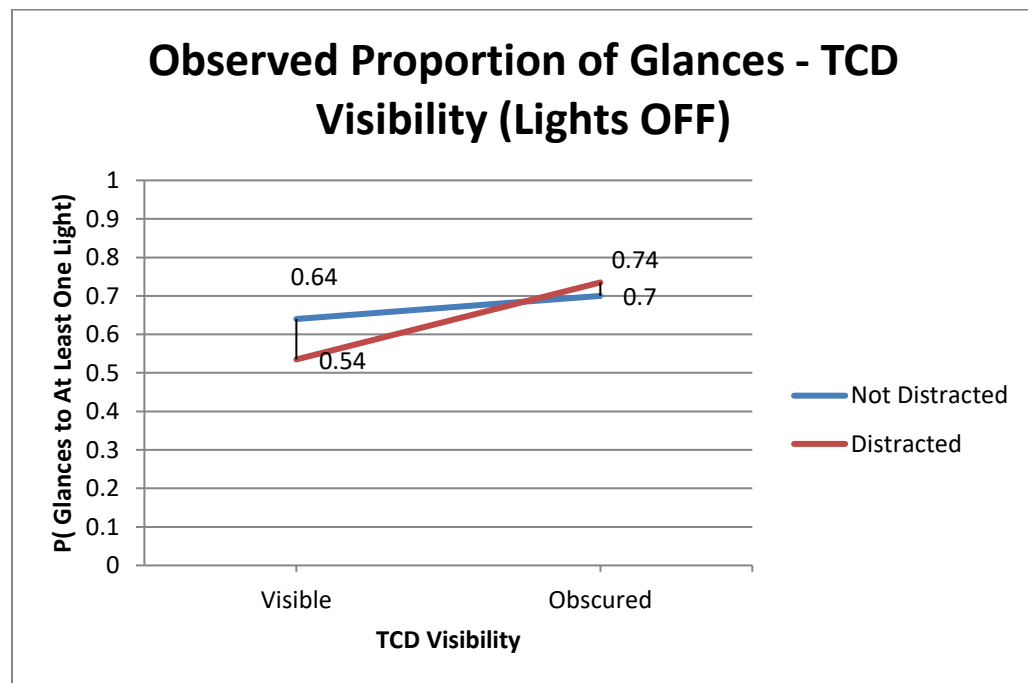


Figure 38: Proportion of Glances in No Stop Required Scenarios - Markings

Table 15: Summary of Means Proportion of Glances for Scenarios Where No Stop is Required (Markings Present)

Scenarios	Control Mean	Control SD	Radio Mean	Radio SD	Cell Mean	Cell SD
B2 - CA,V,OFF	0.64	.11	.39	.12	.69	.12
B4 - CA,O,OFF	.71	.11	.62	.12	.71	.12
T9 - NCA,O,OFF	.36	0.50	.23	.44	.46	.52
T11 - NCA,V,OFF	.86	0.36	.69	.48	.77	.44

A post-hoc pairwise comparison of the various groups for the scenarios above, showed the following results:

- For B2 - CA,V,OFF results showed that the biggest mean difference in the proportion of glances was between the cell phone participants and the radio group .308(95% CI -.096 to .712) though the results were not significant, $p = .201$.
- For the B4 - CA,O,OFF scenario, results show the largest mean difference in the proportion of glances between participants on the cell phone and on the radio .231 (95%CI -.265 to .528), although not significant, $p = 1$.
- For the T9 - NCA,O,OFF scenario, the largest mean difference in the proportion of glances was between the cellphone and the radio groups .231(95% CI -.165 to .627), although not significant, $p = .482$.

- Lastly, for the T11 - NCA,V,OFF, the largest mean difference was between the control and the radio group .165(95% CI -.224 to .554), though the results are not significant, $p = .920$.

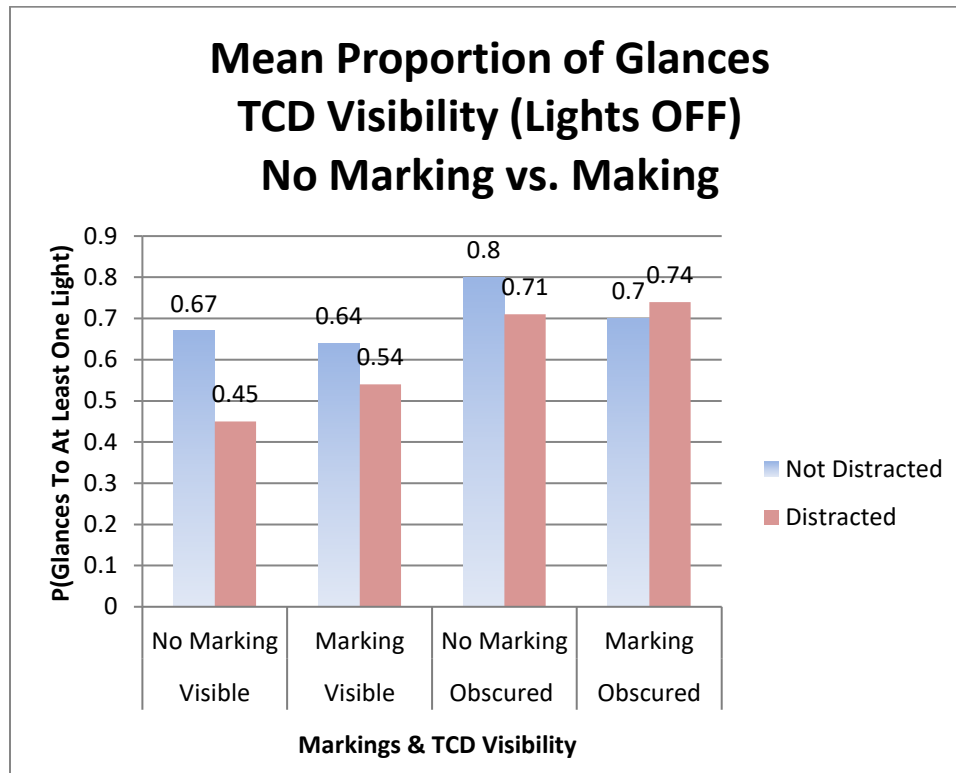


Figure 39: Mean Proportion of Glances – TCD Visibility (Lights OFF)

4.2.2.3 Standard Scenarios Hypothesis 1 Part A Discussion

Although the results discussed showed no statistical significance, it seems that the largest differences in the proportion of glances are between the distracted participants, especially when there is a car ahead. It appears that distracted participants are heavily relying on the car ahead to provide a clue as to what their driving behavior should be.

In particular, scenario NCA, O, OFF shows to have some sort of impact on the drivers, because the proportion of glances taken to at least one of the lights, significantly decreases for this situation. The combination of not having a car ahead to provide for clues, coupled with the TCD's being obscured and not flashing (OFF) creates a situation where the driver becomes complacent and in the case of the control drivers, who are not performing a task, too lazy to look at the lights. However; it is possible that not having a car ahead gives the participant direct view of the retroreflective markings, helping them decide there is no need to glance at the lights in order to obtain the information they need to complete a safe crossing.

The smaller proportion of glances (when compared with the other scenarios) during the CA,V,OFF scenario seems to point to the fact that even when the lights are visible, distracted participants and possibly some control participants, are using the car ahead as an indicator of what is happening immediately ahead. It seems as though not having a car ahead with obscured TCD's and having a car ahead with visible TCD's can both be detrimental to drivers' performance, especially when performing a secondary task.

b) Scenarios where driver needs to stop

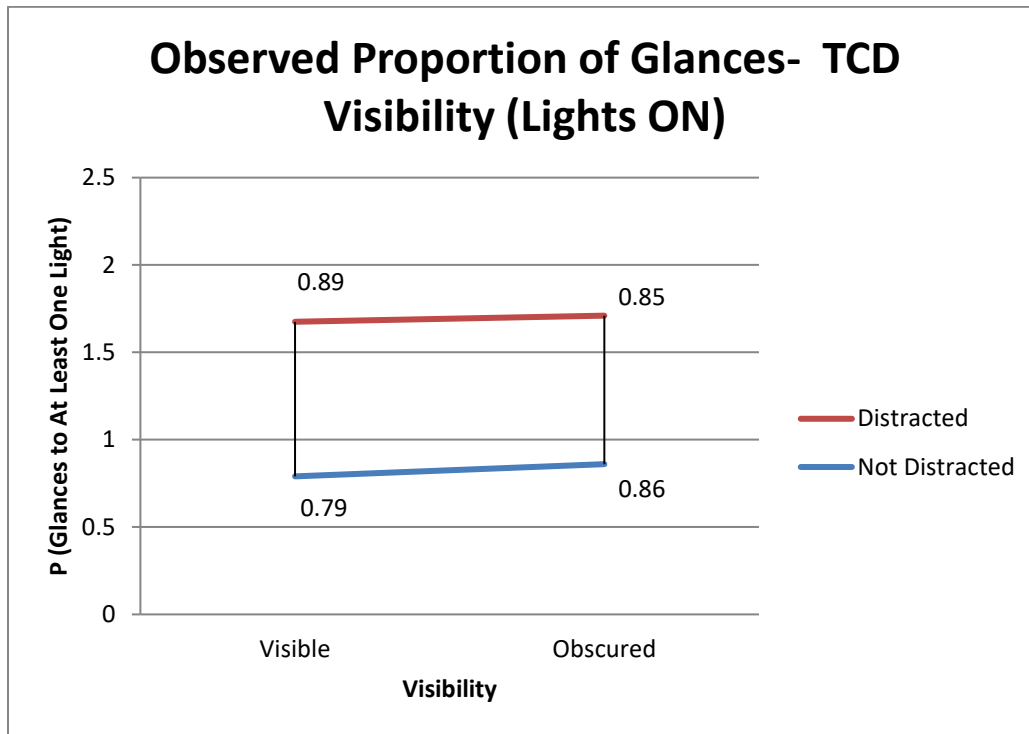


Figure 40: Proportion of Glances in Stop Required Scenarios - Markings

Table 16: Summary of Means for Scenarios Where Stop is Required (Markings Present)

Scenario	Control Mean	Control SD	Radio Mean	Radio SD	Cell Mean	Cell SD
T8 - CA,V,ON	.79	.11	.85	.12	.92	.12
T10 - CA,O,ON	.86	.11	.85	.12	.85	.12
B5 - NCA,O,ON	.79	.43	.77	.44	.92	.28
B3 - NCA,V,ON	.93	.27	.69	.48	.92	.28

A post-hoc pairwise comparison was also performed between the groups, for the scenarios where a stop was required.

Results show:

- For the B3 - NCA,V,ON results showed the largest difference between the control and the radio group, although results not significant, $p = .920$.
- For the B5 - NCA,O,ON, the largest mean difference in the proportion of glances to at least one of the lights was between the cell phone and the radio group though $p=1$, and results not statistical.
- For the T8 - CA,V,ON scenario, the largest mean difference was between the cell phone and the control group, results show no statistical significance, $p=1$.
- For the T10 - CA, O, ON scenario, there was an equal mean difference between the control group and the radio group .011(95% CI -.386 to .408, and the control group and the cell phone group .011(95% CI -.386 to .408) though this difference showed no significant, $p = 1$.

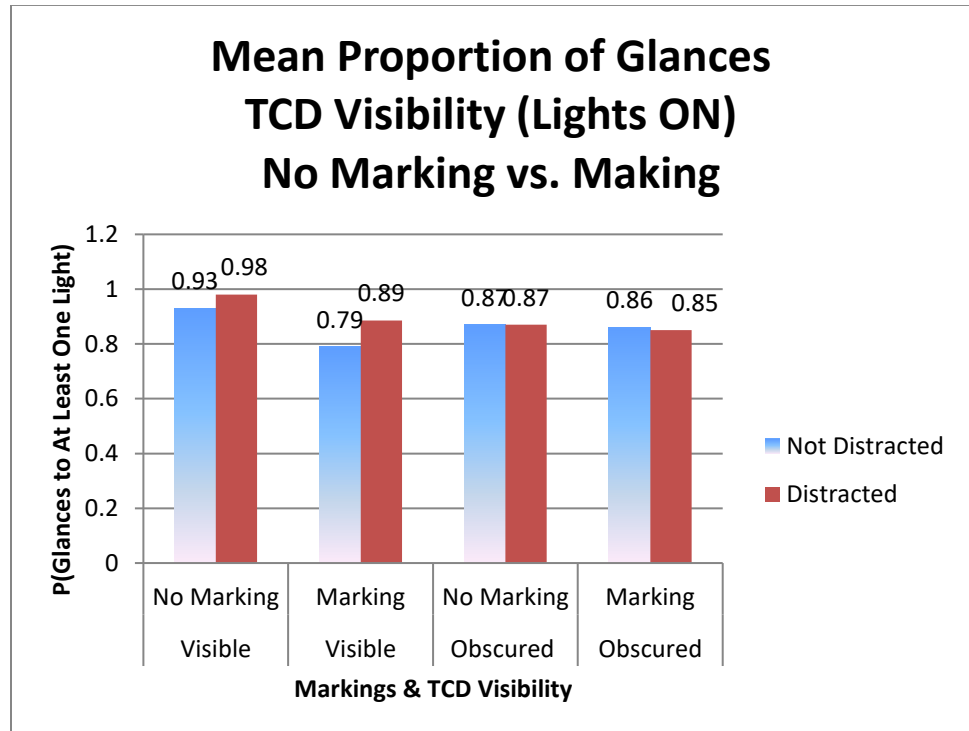


Figure 41: Mean Proportion of Glances – TCD Visibility (Lights ON) M vs. NM

4.2.2.4 Standard Scenarios Hypothesis 1 Part B Discussion

in every scenario described above, a driver is expected to stop, because the lights are flashing. In general, drivers fare really well with these scenarios because the appearance of flashing lights is most likely attracting their attention, even when no car ahead.

In the NCA,O,ON scenario, participants in the cell phone group looked to at least one of the lights at a higher proportion than the control group and the radio group. This is surprising, since one may think that the cognitive distraction may have an impact in this scenario when

there is no car ahead and the lights are obscured. However; it could be that since the lights are obscured, as they start flashing, the driver is immediately able to detect something “different” happening, and as a result, glance in the direction of the lights.

For scenario CA,O,ON the proportion of drivers looking to at least one of the lights is exactly the same. It is no surprise however, since in this scenario all drivers had to stop behind the vehicle due to a train completing a crossing. What is surprising however; is that not all drivers looked to at least one of the lights when stopped, which confirms that there is a proportion of drivers, both distracted and non-distracted, using the car ahead as an indication of how to proceed forward.

4.2.2.5 Standard Scenarios Hypothesis 2

Here I am focusing just on the subset of distracted and undistracted drivers who have glanced at the flashers. I am predicting the same differences here between the driver behaviors of the drivers who are and are not distracted as I predicted for experiment 1. Since I am conditionalizing on both sets of drivers glancing at the flashers, there will be no difference in their glance patterns to the flashers and warning signs. I am also expecting that the differences will be greater in crossings with the standard treatment than crossings with the supplemental treatment.

To test this hypothesis, scenarios B3 - NCA,V,ON and B5 - NCA,O,ON analyzed across all three groups since these are the two standard scenarios where participants’ compliance is

scored (stopping or not stopping) for the standard scenarios. Only those participants who were scored as glancing were then considered for the compliance analysis. An independent samples t-test was used to test the hypothesis.

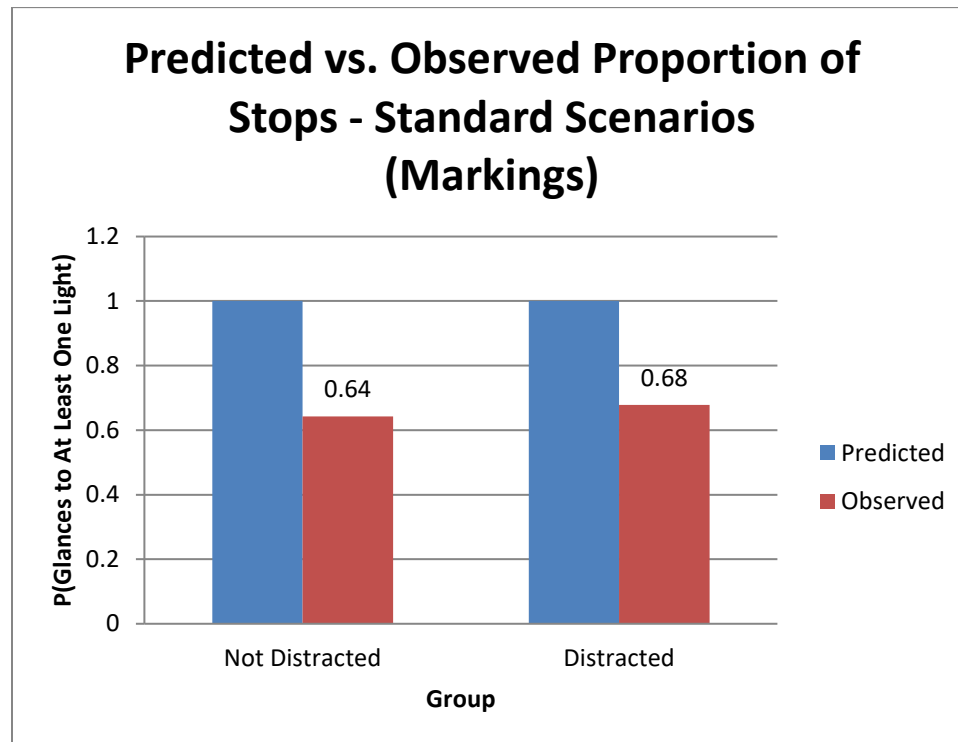


Figure 42: Predicted vs. Observed Proportion of Stops – Standard Scenarios

Table 17: Proportion of Stops for Scenarios of Interest

Scenario	Proportion of Stops		
	Control	Radio	Cell
B3	0.85	0.57	0.86
B5	0.43	0.57	0.71

Results show:

- There was a significant difference in the number stops between the control group and the cell phone group, $t(23) = 2.769$, $p = .011$. There was also, a significant difference between means ($p < .05$), and therefore, I reject the null hypothesis that the mean proportion of stops is equal, and accept the alternative hypothesis.
- There was a statistical significant difference in the mean number of stops between the control group and the radio group but not the way one might expect. The control group stopped less than the radio group -0.28 (95% CI, -0.51 to $-.054$, $t(34.460) = -2.518$, $p = .017$ and as a result, reject the null hypothesis.
- There was no statistical significant difference in the mean number of stops between the radio group and the cell phone group, $t(18) = 1.837$, $p = .083$.

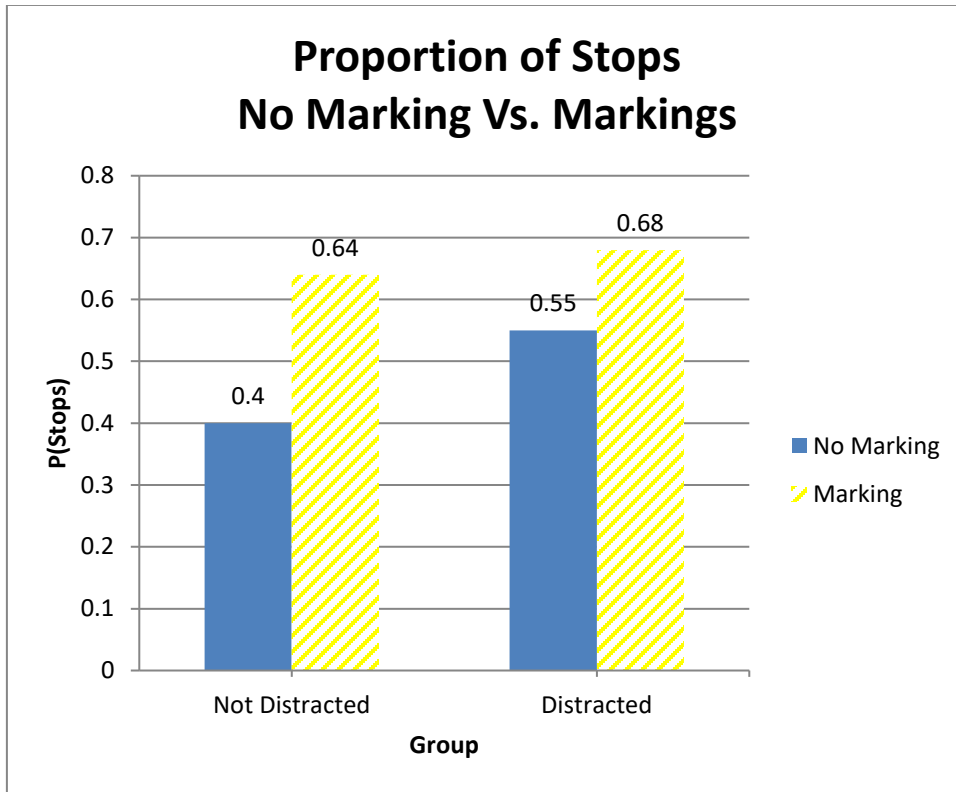


Figure 43: Proportion of Stops No Markings vs. Markings

4.2.2.6 Standard Scenarios Hypothesis 2 Discussion

The analysis of compliance for B3 - NCA,V,ON and B5 - NCA,O,ON showed that there is some effect of load for participants on the cell phone which may cause them to stop less even when there is no car ahead.

Although it is surprising that the control participants stopped less, is possible that since they were scored as glancing they may have determined that no stop was needed further back from the crossing, and as a result either didn't see the lights come on (even though they

glanced) or couldn't stop in time after detecting the lights. In this instance, a participant who is not distracted may be able to associate the dynamic envelope markings with the crossing, and decide earlier on whether there is a need to stop.

In the case of the distracted participants, their awareness of being distracted could have caused them to glance more as they were approaching the crossing, particularly because they may not have taken a glance earlier on due to being distracted. The lights turning flashing (ON), may have been the factor that alerted the driver of the need to stop at.

4.2.2.7 Trick Scenarios Hypothesis

For the Truck Trick (TT) and Bus Trick (BT) scenarios, it is predicted that distracted drivers will glance less often at the flashing lights right before they enter the grade crossing than drivers who are not distracted. For the TT and BT scenarios, it is predicted that the distracted drivers will comply (stop) less than the drivers who are not distracted. I am predicting that among drivers who glance, the effects of distraction will be smaller in the supplemental treatment than they will be in the standard treatment.

The following glance data for the Trick/ No Trick scenarios was used to test the hypothesis.

Table 18: Proportion of Glances to At Least One Light - Markings

Scenario	Group		
	Control	Radio	Cell
BnT	0.79	0.77	0.85
BT	0.93	0.62	0.77
TnT	0.93	0.92	0.92
TT	0.86	0.77	0.92

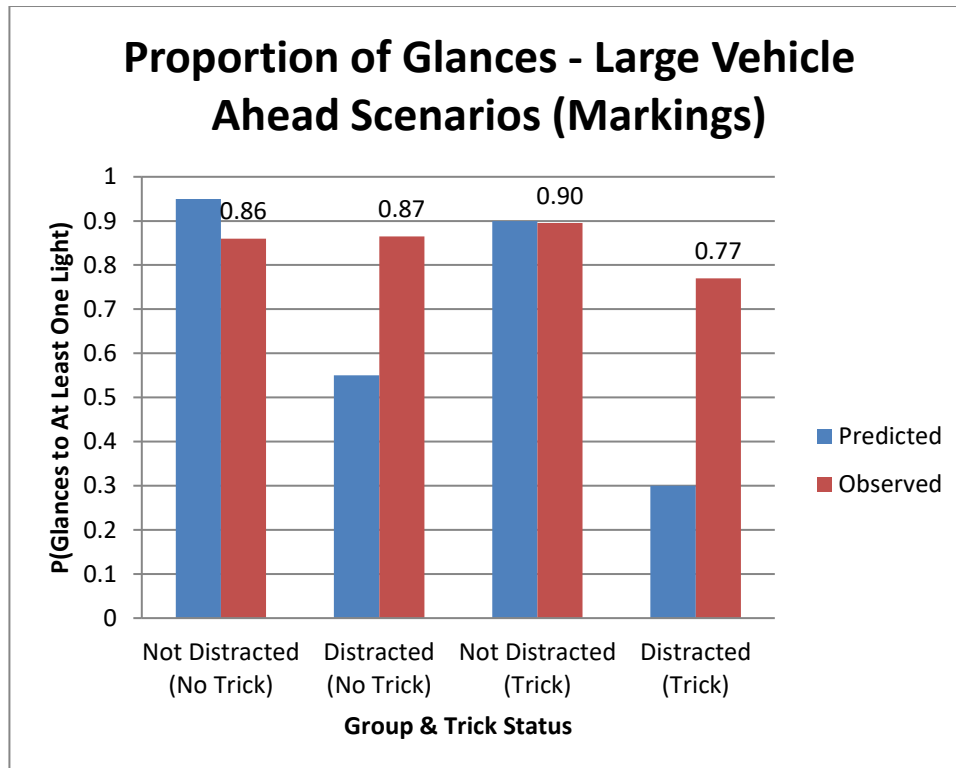


Figure 44: Proportion of Glances – Large Vehicle Ahead (Markings)

One-way Repeated Measures ANOVA was initially used to determine whether there was in fact a statistical significant difference in the proportion of glances taken to at least one of the lights between the groups for Trick Scenarios with markings present. Results showed that in fact there was a statistical significant difference in the proportion of glances taken to at least one of the lights between groups, when there was a large vehicle ahead $F(2.516, 98.108) = 4.292, p = 0.010$.

Glance Analysis for No Trick/Trick Scenarios

A series of independent sample t-tests were then used to compare the differences in the proportion of glances at each Trick Scenario between the groups. Results for the t-tests show:

Bus no Trick (BnT)

- There was no statistical significant difference between the proportion of glances taken by the control group and that of the radio group, the control group looking $t(24.720), = -.099, p < 0.01$.
- There was a statistical significant difference between the proportion of glances taken by the control group and the cell phone group, $t(24.942) = .392, p=0.699$.
- There was no statistical significant difference in the proportion of glances taken by the radio group, $t(23.445) = .480, p = .635$.

Bus Trick (BT) Scenario

- There was a statistical significant difference in the proportion of glances taken between the control group and the radio group, $t(25) = -2.031$, $p = 0.05$.
- There was no statistical significant difference between the proportion of glances taken by the control group, and the cell phone group $t(25) = -1.15$, $p = .272$.
- There was no significant difference in the proportion of glances taken by the radio group and the cell phone group $t(23.52) = .828$, $p = .416$.

Truck no Trick (TnT)

- There was no statistical significant difference in the proportion of glances taken by the control and the radio group, $t(24.679) = -.052$, $p = .959$.
- There was no statistical significant difference between the proportion of glances taken by the control group and the cell phone group $t(24.679) = -.052$, $p = .957$.
- There was no statistical significant difference in the proportion of glances taken by the radio group and the cell phone group, $t(24) = 0$, $p = 1$.

Truck Trick (TT)

- There was no statistical significant difference between the proportion of glances taken by the control group and the radio group, $t(23.392) = -.565$, $p = .577$.

- There was no statistical significant difference between the proportion of glances taken by the control group and the cell phone group $t(24.142) = .532, p = .599$ slightly more glances on average.
- There was no statistical significant difference in the proportion of glances taken between the radio group and the cell phone group, $t(24) = 1.06, p = .296$.

The results from the statistical analysis have been summarized in **Table 19** below.

Table 19: Trick/No Trick Scenarios Glance Analysis Summary of Values

Scenario	Comparison	Mean Difference*	95% Confidence Interval	P-Value
BnT	Control vs. Radio	-0.016	-.359 to .326	0.922
	Control vs. Cell	0.06	-0.257 to .378	0.699
	Radio vs. Cell	0.08	-.253 to .407	0.635
BT	Control vs. Radio	-0.31	-.644 to 0.017	0.05
	Control vs. Cell	-0.15	-0.444 to .126	0.272
	Radio vs. Cell	0.15	-.230 to .538	0.416
TnT	Control vs. Radio	-0.005	-.221 to .210	0.959
	Control vs. Cell	-0.005	-.221 to .210	0.959
	Radio vs. Cell	-0.005	-.221 to .210	0.959
TT	Control vs. Radio	-0.08	-.409 to .233	0.577
	Control vs. Cell	0.07	-.189 to .321	0.532
	Radio vs. Cell	0.15	-.143 to .450	0.296

*The first group is subtracted from second group (i.e, $M_{\text{control}} - M_{\text{radio}}$)

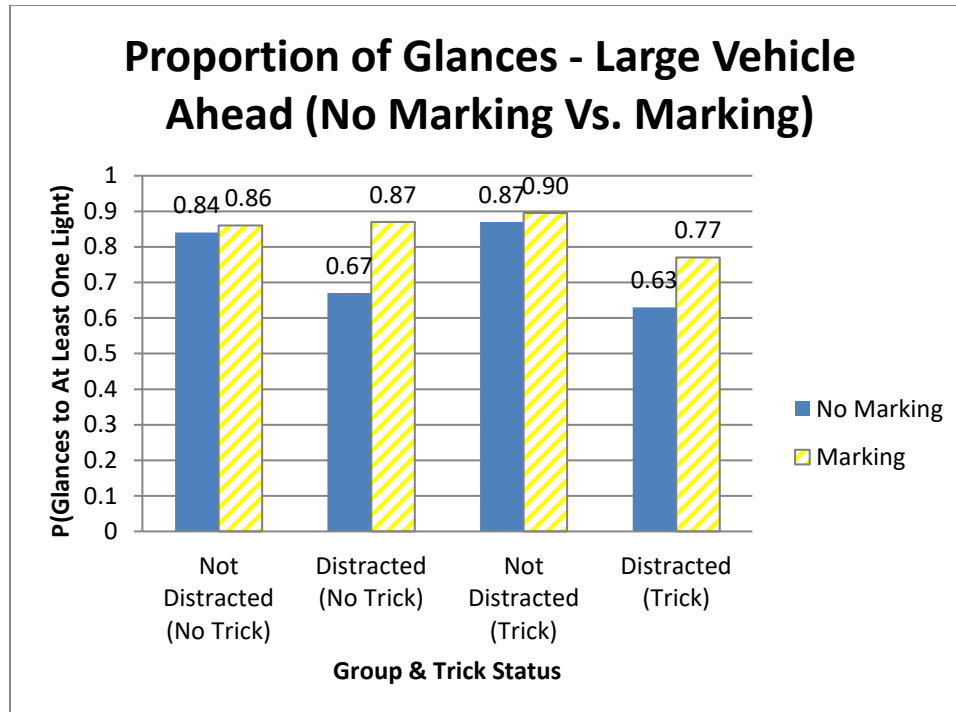


Figure 45: Proportion of Glances – Large Vehicle Ahead (No Marking vs. Marking)

4.2.2.7.1 Trick Scenarios Hypothesis Glances Discussion

The analysis of glance proportions when there is a large vehicle ahead shows that the differences between groups in the proportions of glances taken to at least one of the lights are very small. In fact, it seems that at times the distracted drivers are taking a slightly higher proportion in glances to at least one of the lights.

One may expect that if the participant is distracted, glancing behavior may be impacted, however, it seems that having a large vehicle ahead really cues the driver to glance more. A speculation for this effect may be that all participants, whether distracted or not are pre-empting the behavior of the large vehicle ahead, especially for the bus.

Although the large vehicle is blocking the driver's immediate view ahead, the fact that there are two lanes per approach as the participant approaches the crossing may be a benefit to the driver. The wider road provides a larger field view for the participant thus allowing them to see the light on the left (on opposite approach).

The significant difference between the radio group and the control group for the Bus Trick scenario can potentially be attributed to the participant's previous exposure to the bus during the first scenario. An observed frequent occurrence as seen in the eye tracking videos with the radio group was the participant pressing on the brakes at the very last minute to avoid a collision with the bus due to their unexpected need to stop. It is then possible that during the last scenario (Bus Trick) the participant, although distracted, recalls the behavior of the bus during the first scenario, and as a result starts looking more.

4.2.2.7.2 Trick Scenarios Compliance Discussion

With the above information in mind, I will now look at the compliance performance for all three groups in the Bus Trick (BT) and Truck Trick (TT) scenarios. There was no compliance scored for the Bus no Trick (BnT) and Truck no Trick (TnT) scenarios since participants were caused to stop when the large vehicle ahead did so.

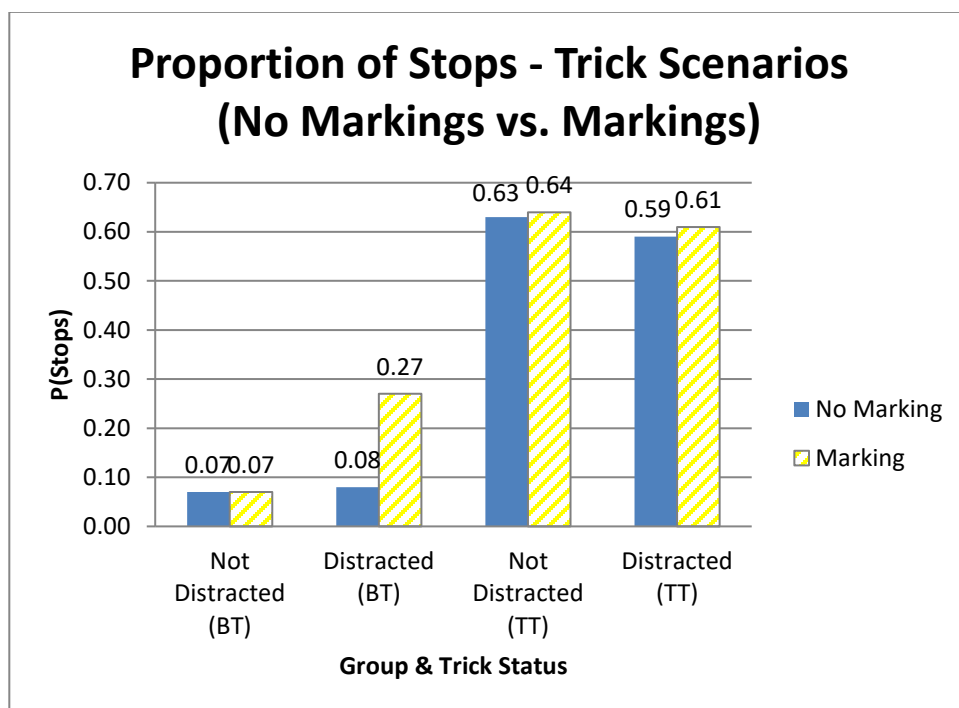


Figure 46: Proportion of Stops in Trick Scenarios with Large Vehicle Present – No Marking vs. Marking

A series of independent sample t-tests were used to compare the differences in the proportion of stops at each Trick Scenario between the groups. Results for the t-tests show:

Bus Trick

- There was no statistical significant difference in the mean proportion of stops between the control group and the radio group, $t(23.88) = 593$, $p = .559$.
- There was no statistical significant difference in the mean proportion of stops between the control group, $t(26) = 1.894$, $p = .07$.
- There was no statistical significant difference between the radio and the cell phone, $t(26) = 1.302$, $p = .204$.

Truck Trick

- There was no statistical significant difference in the mean proportion of stops between the control group, $t(26.927) = -1.301$, $p = .204$.
- There was no statistical significant difference in the mean proportion of stops between the control group and the cell phone group, $t(20.94) = -.271$, $p = .789$.
- There was no statistical significant difference between the radio and the cell phone, $t(20.92) = .653$, $p = .521$.

Table 20: Trick Scenarios Compliance Analysis Summary of Values

Scenario	Comparison	Mean Difference*	95% Confidence Interval	P-Value
----------	------------	------------------	-------------------------	---------

BT	Control vs. Radio	0.07	-.176 to .319	0.559
	Control vs. Cell	0.29	-.029 to .600	0.07
	Radio vs. Cell	0.21	-.029 to .600	0.204
TT	Control vs. Radio	-0.24	-.626 to .139	0.204
	Control vs. Cell	-0.07	-.375 to .717	0.789
	Radio vs. Cell	0.17	-.619 to .476	0.521

*The first group is subtracted from second group (i.e, Mcontrol-Mradio)

The compliance behavior analysis for the trick scenarios shows that the high proportion of glances participants across all groups are taking for these scenarios is not helping them stop, especially when the large vehicle ahead is a bus.

First, let's consider the Bus Trick (BT) scenario: First, it is surprising and almost unexpected that the cell phone group would be stopping at higher proportions than both the radio group and the non-distracted drivers stop in low proportions for the bus trick condition. Let's recall that in this situation the bus stops (because all buses have to stop at railroad crossings) and then proceeds forward. It appears that after the bus moves forward, the participants do their "due diligence" by taking a glance to at least one of the lights. However, since the lights are OFF from the point where the driver "launches" they decide is safe to cross. It was also a common occurrence for drivers to see the light flashing at the last second, yet not have enough time to stop.

In the case of the Truck Trick scenario all participant groups increased the proportion of glances to at least one of the lights when compared to the BT scenario. An important reminder is that during the Truck no Trick (TnT) scenario, the bus stopped for flashing lights and as a result so did the participant driver. It is my believe that since the truck “had a reason” to stop for the first scenario, when the truck re-appears for the last “trick” scenario, participants associate the truck with stopping for flashing lights. This memory of the truck stopping for the lights in addition to the added visibility of the tracks, as shown in **Figure 47** below, enhanced the presence of the markings. This combination can trigger safer behavior across all drivers, even those who are distracted.

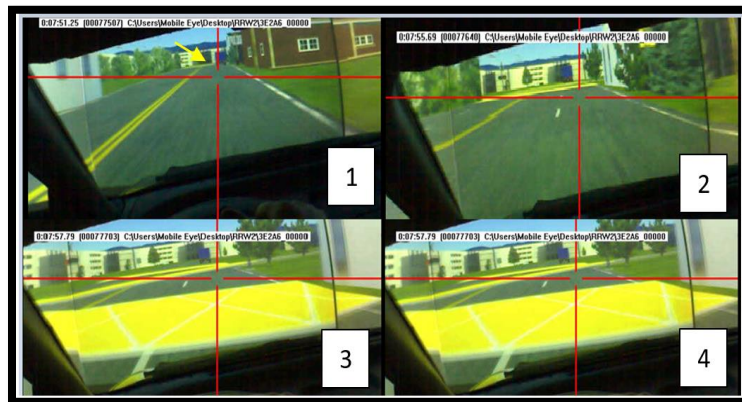


Figure 47: Driver's View of Markings on Approach to Grade Crossing

4.3 Differences between No Markings (Experiment 1) and Markings (Experiment 2)

In order to determine the impact of the dynamic envelope markings on driver behavior, the following comparative analysis was conducted between the No Marking (Experiment 1) and Marking (Experiment 2) conditions.

4.3.1 Glance Comparison for Proportion of Glances To At least One Light

A Two-way ANOVA analysis was undertaken to compare the proportion of glances taken by groups for conditions with no car ahead, car ahead, and large vehicle ahead. An analysis of compliance for Trick Scenarios was also completed.

Table 21: Car Ahead Scenarios

B2 - CA,V,OFF
B4 - CA,O,OFF
T8 - CA,V,ON
T10 - CA,O,ON

Results from the Univariate Linear Model showed that there was a statistical significant interaction between groups and the presence of a car ahead for the proportion of glances to at least one of the lights $F(15,308) = 4.213, p = .001$. A post-hoc pairwise comparison with Bonferroni adjustment analysis showed the following differences:

Table 22: Summary of Mean Glance Differences for Groups – Car Ahead Scenarios

Scenarios	Control (Markings-No Markings)			Radio (Markings-No Markings)			Cell (Markings - No Markings)		
	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value
B2 - CA,V,OFF	-0.048	0.162	1	-0.433	0.151	0.067	0.239	0.182	1
B4 - CA,O,OFF	0.586	0.174	0.013	0.248	0.153	1	0.492	0.177	0.085
T8 - CA,V,ON	0.505	0.156	0.02	0.563	0.151	0.004	0.615	0.182	0.012
T10 - CA,O,ON	0.795	0.156	0.001	0.583	0.515	0.002	0.735	0.182	0.001

Car Ahead Scenarios:

- For CA,V, OFF, the largest statistical significant difference was seen between Control(M) and Cell (NM), $F(5,308) = 5.349$, $p = .001$.
- For CA,V ON, there no statistical significant difference between Control(M) and Radio(NM) $F(5,308) = 1.278$, $p = .008$.
- For CA,V ON, there was a statistical significant difference between Control(M) and Cell (NM), $F(5,308) = 1.278$, $p = .024$.
- For CA,V ON, there was a statistical significant difference between Radio(M) and Radio (NM) with the Radio(M) $F(5,308) = 1.278$, $p = .004$.
- For CA,V ON, there was a statistical significant difference between Radio(M) and Cell (NM), $F(5,308) = 1.278$, $p = .012$.
- For CA,V ON, there was a statistical significant difference between Cell(M) and Radio (NM), $F(5,308) = 1.278$, $p = .004$.

- For CA,V ON, there was a statistical significant difference between Cell(M) and Cell (NM), $F(5,308) = 1.278$, $p = .012$.
- For CA,O,OFF, there was a statistical significant difference between Control(M) and Control (NM), $F(5,308) = 4.988$, $p = .003$.
- For CA,O,OFF, there was a statistical significant difference between Control(M) and Cell (NM), $F(5,308) = 4.988$, $p = .013$.
- For CA,O,ON, there was a statistical significant difference between Control(M) and Control (NM), $F(5,308) = 11.436$, $p = .001$.
- For CA,O,ON, there was a statistical significant difference between Control(M) and Radio (NM) with the Control(M), $F(5,308) = 11.436$, $p = .001$.
- For CA,O,ON, there was a statistical significant difference between Control(M) and Cell (NM), $F(5,308) = 11.436$, $p = .001$.
- For CA,O,ON, there was a statistical significant difference between Radio(M) and Radio (NM), $F(5,308) = 11.436$, $p = .002$.
- For CA,O,ON, there was a statistical significant difference between Radio(M) and Cell (NM), $F(5,308) = 11.436$, $p = .001$.
- For CA,O,ON, there was a statistical significant difference between Cell(M) and Control (NM), $F(5,308) = 11.436$, $p = .001$.
- For CA,O,ON, there was a statistical significant difference between Cell(M) and Cell (NM), $F(5,308) = 11.436$, $p = .001$.

- For CA,O,ON, there was a statistical significant difference between Cell(M) and Radio (NM), $F(5,308) = 11.436$, $p = .002$.

For ease of comparison, the statistical significant comparisons described above have been summarized in **Table 23** below.

Table 23: Statistical Significant Comparisons - Car Ahead Scenarios

B2 - CA,V,OFF	B4 - CA,O,OFF	T8 - CA,V,ON	T10 - CA,O,ON
Control (M) & Cell (NM)	Control (M) & Control (NM)	Control (M) & Radio(NM)	Control (M) & Control (NM)
	Control (M) & Cell (NM)	Control (M) & Cell (NM)	Control (M) & Radio (NM)
		Radio (M) & Radio (NM)	Control (M) & Cell (NM)
		Radio (M) & Cell (NM)	Radio (M) & Radio (NM)
		Cell (M) & Radio (NM)	Radio (M) & Cell (NM)
		Cell (M) & Cell (NM)	Cell (M) & Control (NM)
			Cell (M) & Cell (NM)
			Cell (M) & Radio (NM)

No Car Ahead Scenarios:

Table 24: No Car Ahead Scenarios

B3 - NCA,V,ON
B5 - NCA,O,ON
T9 - NCA,O,OFF
T11 - NCA,V,OFF

There was no statistical significant interaction between groups and the no car ahead condition, for the proportion of glances to at least one of the lights $F(15,308) = 1.037, p = .416$. However, a summary of No Marking (NM) and Marking (M) mean differences for all groups is summarized below.

Table 25: Summary of Mean Glance Differences for Groups – No Car Ahead Scenarios

Scenarios	Control (Markings-No Markings)			Radio (Markings-No Markings)			Cell (Markings - No Markings)		
	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value
B3 - NCA,V,ON	-0.067	0.157	1	0.113	0.155	1	0.034	0.187	1
B5 - NCA,O,ON	-0.081	0.160	1	-0.02	0.155	1	0.145	0.187	1
T9 - NCA,O,OFF	0.224	0.16	1	-0.19	0.155	1	0.017	0.187	1
T11 - NCA,V,OFF	0.19	0.163	1	0.113	0.155	1	0.214	0.187	1

For Large Vehicle Ahead Scenarios:

Table 26: Large Vehicle Ahead Scenarios

B1 - BA,V,OFF (BnT)
B6 - BA,O,OFF (BT)
T7 - TA,V,ON (TnT)
T12 - TA,O,OFF (TT)

Glances

An Univariate Linear Model test showed that there was a statistical significant interaction between groups and the presence of a large vehicle ahead for the proportion of glances to at least one of the lights $F(15,308) = 2.096, p = .010$.

A post-hoc pairwise comparison with Bonferroni adjustment shows the following results:

- For BnT there was a statistical significant difference between Radio (M) and Radio (NM), $F(5,308) = 5.700 p = .001$.
- For BnT there was a statistical significant difference between Cell (M) and Radio (NM), $F(5,308) = 5.700 p = .001$.

Table 27: Summary of Mean Glance Differences for Groups – No Trick/Trick Scenarios

Scenarios	Control (Markings-No Markings)			Radio (Markings-No Markings)			Cell (Markings - No Markings)		
	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value
BnT	0.014	0.141	1	-0.506	0.137	0.004	-0.179	0.165	1
BT	0.071	0.141	1	0.069	0.137	1	0.12	0.165	1
TnT	-0.062	0.141	1	-0.081	0.137	1	0.077	0.165	1
TT	-0.124	0.141	1	0.126	0.137	1	-0.256	0.165	1

Compliance

An Univariate Linear Model test showed that there was there was no statistical significant interaction between groups and the presence of a large vehicle ahead for the proportion of stops made for the trick scenarios $F(15,316) = .841, p = .631$. A summary of the mean differences in proportion for the number of stops between groups for the No Marking (NM and Marking (M) condition is shown below.

Table 28: Summary of Mean Compliance Differences for Groups – No Trick/Trick Scenarios

Scenarios	Control (Markings-No Markings)			Radio (Markings-No Markings)			Cell (Markings - No Markings)		
	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value	Mean Difference	SE	P-Value
BnT	-0.457	0.169	0.11	-0.171	0.169	1	-0.221	0.184	1
BT	-0.029	0.169	1	0.029	0.169	1	-0.169	0.184	1
TnT	0.019	0.184	1	-0.076	0.169	1	-0.266	0.184	1
TT	-0.011	0.161	1	0.15	0.161	1	-0.24	0.184	1

4.4 Discussion

Results from the second experiment show that drivers benefitted tremendously from the addition of the dynamic envelope markings. In fact, the mean proportion of glances significantly increased across all three groups when for the marking scenarios.

One of the important findings of this experiment is that the visibility of the lights and the presence of a car ahead are significantly important aspects for driver safety in the vicinity of crossings. Results show the most significantly statistical significance for scenarios with a car ahead. It is no secret that drivers (and by the results previously discussed) have a tendency to focus on the car ahead to obtain clues for what is happening ahead of them on the road. This is particularly true for drivers who are distracted.

The cell phone group fared much better than the radio group, and it is no surprise since using the cell phone is a much more routine activity than changing the radio with the buttons on the dashboard. In fact, many participants commented that “in my car, I use the buttons on the steering wheel to change the radio station” and so perhaps this is a factor that may contribute to their performance for scenarios with no car ahead.

For the most statistical significant scenario T10 - CA, O, ON in the comparisons table, **Table 23.** Every single group of paired comparisons benefited from the use of the markings. This is a key factor because in this scenario, although the lights are obscured, participants increased the proportion of glances to the lights in statistical significant proportions when the markings were present. Although in these scenarios the participant had to stop behind the car ahead, the fact that participants in second experiment looked to at least one of the lights in larger proportions than the drivers in experiment 1, validates the impact of these markings, especially when the driver is distracted.

Although scenarios with no car ahead showed to have no interaction between the groups, it is important to note that these may be the situations where the drivers could benefit most from the presence of markings. Scenario B3 - NCA,V,ON showed the largest difference between the control and the radio group, with the control group taking a slightly higher proportion of glances. This difference corroborates the need for lights to be properly maintained, and for the rail right away to remain free of obstructions.

In addition to the flashing lights and the markings, the W10-1 advance warning sign was also present at all crossings, but as expected and noted by literature, drivers miss the sign most of the time. Let's consider **Figure 48** below, which shows a comparison of the proportion of glances taken to the warning sign for the scenarios of interest.

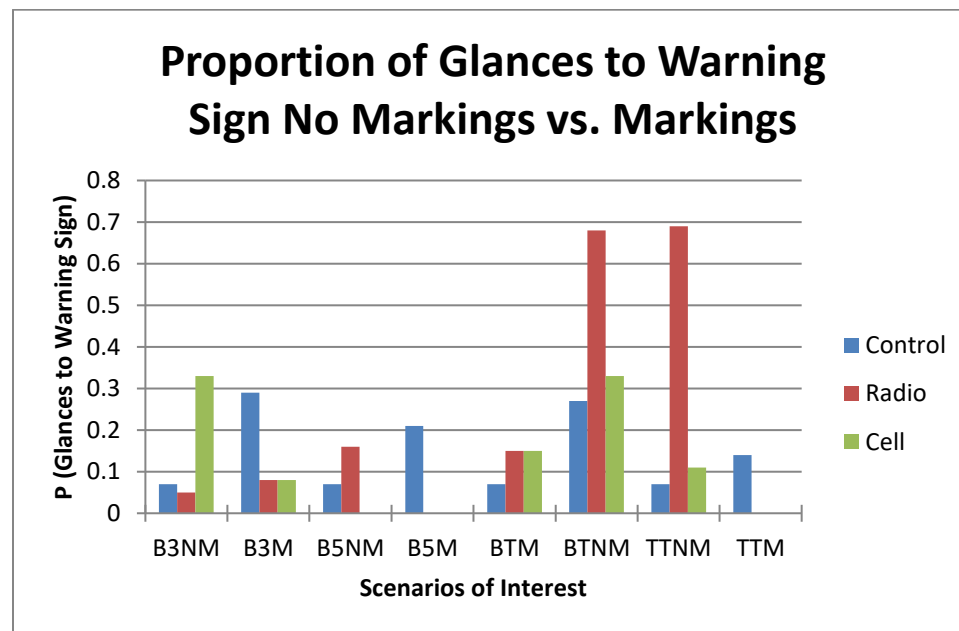


Figure 48: Proportion of Glances to Warning Sign – NM/M Scenarios of Interest

In general, the proportion of glances is not impressive, particularly for the control group. Even when not distracted, most participants missed the advance warning sign. With the exception of the BT- No Marking and TT- No Marking where radio participants glanced in higher proportions, and it's possible that these could be the same drivers, given that all participants saw all twelve drives. In the B5 – NCA,O,ON Markings scenario, only the control group glanced at the sign. While these results don't indicate that the sign is useless per se, it does point to the fact that for passive crossings, where the W10-1 warning sign and the crossbuck are present, a

driver may have no idea that they are approaching a railroad crossing zone, and unknowingly place themselves in harm's way.

Scenario B3- NCA,V,ON deserves special consideration since this crossing is at the exit of a horizontal curve. Before the markings, control participants almost completely missed the sign, but after the markings, these participants glanced at the sign in greater proportions. In this case, cell phone drivers behaved just opposite, with drivers taking a higher proportion of glances before the markings but not after the markings.

Although participants glanced in larger proportions in experiment 2, this was not the case with compliance. The Bus Trick (BT) scenario presents a curious phenomenon, since participants glanced in high proportions (Control = 0.93, Radio = 0.62, Cell = 0.77), yet these glances did not translate to stopping behavior.

Table 29: Proportion of Glances & Stops-Trick Scenarios

		Control	Radio	Cell
BT	Glance %	0.93	0.62	0.77
	Yield %	0.07	0.14	0.36
TT	Truck %	0.86	0.77	0.92
	Yield %	0.64	0.43	0.79

There are several issues at play for this scenario since there are two lanes per approach to the crossing which could provoke drivers to instinctively pass the bus on the left lane – bus disrespect. As previously discussed, drivers dislike slow moving ahead, especially buses. In fact, this scenario could place the driver in a fatal situation since a) the driver is less willing to scan for reasons why the bus stopped, and b) less likely to stop.

Although the argument of road geometry could hold for the BT scenario, in the case of the TT (same scenario, the only difference is the vehicle) this argument is null. In fact, for the TT scenario, participants stopped in much larger proportions, although as previously discussed, not statistically significant. This leads me to believe that the issue lies on the participant's first experience with these vehicles (BnT, TnT). Let's recall that for the No Trick scenarios both the bus, and the truck came to a stop, but for different reasons. The bus is mandated by law to stop at all railroad crossings, and the truck stopped because the lights were flashing.

Taking this into consideration, for participants who are performing the radio task during the BnT/TT scenario, the sudden stop of the vehicle in front may remind them that a) they are distracted and b) be cautious. If this is true this would explain why participants in the radio group glanced in unexpectedly large proportions and stopped almost .30 more frequently for the TT scenario, than for the BT scenario.

Taking these observations in consideration then it is safe to say that the markings were effective in a range of situations, particularly those where the driver was distracted, and/or the lights were obscured.

CHAPTER 5

CONCLUSION

The objectives of this dissertation were to address the role that distraction has on the effectiveness of warning devices (crossbuck with flashing lights) when the driver is performing a distracting task; and based on the evaluation of the warning configuration, determine a potential improvement to the current warning devices configuration which can provide a greater level of awareness to the road user of the potential presence of a train. Both objectives were accomplished and important lessons were learned.

Grade crossings present a challenge for everyone involved. From the policy-makers and enforcement officials puzzled with how to curve incidents and deaths in greater numbers, to the engineers working arduously to improve grade crossing safety, and the public in general, everyone plays a role in maintaining safety.

A key takeaway from this research is that even when the flashers are properly working, if there is an obstruction (whether by vegetation or other factor) the driver may be in danger. Road geometry also plays a big part in driver safety, as crossings located on curves or multi-lane roads create complex situations for the driver to navigate.

The dynamic envelope pavement markings provide a cost effective, and feasible alternative for alerting drivers of a grade crossing ahead. Even in situations where the driver

does not look at the warning sign, and misses the flashers, the markings can add a layer of safety, particularly when a driver is distracted.

Distraction is widely known to be a top contender for the number one cause of crashes in the U.S. While statistics have improved, the numbers are appalling. Given the poor behavior of drivers on approach a grade crossings, the presence of markings can help drivers texting and driving for example, to look up and detect the lights. Of course driver comprehension is at play in all these scenarios.

5.1 Research Limitation

While this research was an important step in reviving the conversation of markings on the dynamic envelope, its success does have limitations. In particular, while these markings may be effective initially, it is unknown whether the “effect” will remain with drivers, or whether it would become as ignored as the advance warning sign.

Another limitation of this research is the lack of knowledge on driver comprehension. Since experimental participants were not surveyed on their comprehension of railroad signage, it’s hard to infer that they understood what was required of them in these situations. In fact, many participants questioned what the proper behavior at these crossings was. On the other hand, over half of participants in the second experiment commented without prompting that they “started associating the markings with the crossings” and while their glances and behavior

show that they saw and then reacted, it makes one question whether this was a result of “something different” on the roadway, or that they truly understood what was required of them in these situations.

5.2 Field Contribution & Future Work

It is my hope that the findings in this study motivate the discussion of feasible, readily-available treatments for use at grade crossings. I hope that my dissertation work will shed some light on addressing the increasing level of distraction, particularly at railroad-highway crossings. Further research needs to be conducted on the impact of these markings with various roadway geometries and weather condition; a driving simulator provides an excellent alternative for testing these concepts before they are made readily available to practitioners.

CHAPTER 6

RESEARCH SUPPORT

This research was supported in part by a grant to Michael A. Knodler Jr., from the New England University Transportation Center and in part by NSF AGEP Grant #0450339 and NIH IMSD Grant # R25GM099649) to Sandra Petersen.

APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT DOCUMENT

PROJECT TITLE: A Driving Simulator Evaluation Of Driver Behavior And Traffic Control Devices At At-Grade Railroad Crossings

PRINCIPAL INVESTIGATOR: Michael Knodler, Ph.D.

RESEARCH SPONSOR: New England University Transportation Center

PURPOSE: The purpose of this study is twofold: (1) to evaluate drivers' response to traffic elements presented through simulation (2) to increase drivers' understanding of traffic devices on the road.

1. PROCEDURE:

You have been selected because you have a valid driver's license, have normal or corrected to normal vision, and have no apparent limitations impeding your ability to drive. Please read this form and ask any questions you have before agreeing to participate in the study.

If you are particularly susceptible to motion sickness please inform the laboratory assistant before starting the experiment. He or she will determine whether you should continue in the experiment.

BACKGROUND INFORMATION: You will be asked to complete a short demographic questionnaire.

TRAINING: You will be seated in the driver's seat in the driving simulator. The driving simulator consists of a Saturn sedan (see picture to the right). The engine has been taken out and the car is unable to move. A three-section screen is placed in front of the Saturn. The screen displays the world ahead of you just as if you were you driving on the open road. The research assistant will show you how to stop and how to turn. You will then learn how to do these maneuvers yourself. It should be no more difficult to learn these maneuvers on the Saturn than it is on any car that you have previously driven.



EYE TRACKER: Before the simulator drives begin, you will also be fitted with a head-mounted eye tracking device that helps us better understand your eye movements during the experiment. The eye tracker is essentially a pair of safety glasses with two miniature cameras mounted on it. The glasses are connected by a small cable to a video recorder. There will then be an eye tracker calibration routine that will take place. The researcher will fit the glasses on you and then ask you to look at certain objects in your field of view. The calibration process will take approximately 5 minutes.

EXPERIMENT: After learning how to drive the simulator, and the proper calibration of the eye tracker, you will begin the experimental session. You will be given a complete set of instructions at that time. The driving portion will consist of one session lasting approximately 20 to 25 minutes. The total drive time is not expected to take more than 45 minutes.

- 2. POSSIBLE RISKS OR DISCOMFORTS:** Benefits of participating in this study include potentially learning how to be a safer driver.

In terms of risks, there is a slight risk of simulator sickness when you operate the driving simulators. A small percentage of participants who drive the simulator may experience feelings of nausea or actual nausea. The experimenters work to minimize this risk, but it is still present. Because of this risk, any person who experiences motion sickness while in a real car should not participate in the experiment. If during the simulator drives, you feel discomfort or nausea, you should inform the experimenter immediately so that the simulation can be stopped. Halting the simulation should quickly reduce the discomfort. If you do not feel better soon after the simulation is halted, we can arrange for someone to drive you home or help you seek medical care if necessary.

There are no known risks related to using the head-mounted eye tracking device.

- 3. SAFEGUARDS:** Safeguards associated with crashes, simulator discomfort during the experiment, and possible difficulties driving home have been mentioned above. Additionally, since the car used in the driving simulator will for most individuals be one with which they are not familiar, a spotter will be present as you enter and exit the vehicle to assure that you don't miss-step or lose your balance.
- 4. WITHDRAWAL:** Participation is strictly voluntary. You are free to withdraw consent and discontinue participation in the study at any time without prejudice. There are no penalties or loss of benefits from not participating or withdrawing from the study, however, you will not be compensated for participation if you voluntarily withdraw.
- 5. CONFIDENTIALITY:** The results of this research may be published and submitted for presentation at professional society meetings and/or used by the approved researchers for internal purposes. No participant will be identifiable from the reports nor will any participant's name or initials be used in the reports. To maintain confidentiality of your records, the researchers will use subject codes, rather than names, to identify all data collected through the questionnaires and during your simulation drives. The data will be secured in the Human Performance Laboratory and will be only accessible by the principal investigator, Dr. Michael Knodler, and any other approved researchers for the study.

It is possible that your research record, including sensitive information and/or identifying information, may be inspected and/or copied by federal or state government agencies, in the course of carrying out their duties. If your record is inspected by any of these agencies, your confidentiality will be maintained to the extent permissible by law.

-
6. **COMPENSATION:** You will be paid **\$20** if you complete the full study session and pro-rated compensation will be provided to you if you choose to end your session early for any reason. For example, if you spend 30 minutes performing the simulation before completion, you will be paid **\$10**.

The University of Massachusetts at Amherst does not have a program for compensating subjects for injury or complications related to human subjects' research but the study personnel will assist you in getting treatment.

7. **QUESTIONS AND ANSWERS:** Should you have any questions about the experiment or any other matter relative to your participation in this project, or if you experience a research related injury as a result of this study, you may call the principal investigator, Professor Michael Knodler, at (413) 545-0228 or mknodler@ecs.umass.edu. If, during the study or later, you wish to discuss your participation or concerns regarding it with a person not directly involved in the research, you can talk with the University of Massachusetts-Amherst's Human Subjects Research Administrator at (413) 545-3428 or humansubjects@ora.umass.edu. A copy of this consent form will be given to you to keep for your records.

8. **SUBJECT STATEMENT OF VOLUNTARY CONSENT**

By signing below, I, the participant, confirm that the experimenter has explained to me the purpose of the research, the study procedures that I will undergo and the benefits as well as the possible risks that I may experience. Alternatives to my participation in the study have also been discussed. I have read and I understand this consent form.

Printed name and signature of participant

Date

9. **EXPERIMENTER STATEMENT**

By signing below, I the experimenter, indicate that the participant has read and had explained to them this study, and that he/she has signed this Informed Consent Form.

Signature of person obtaining informed consent

Date

APPENDIX B

DEMOGRAPHIC QUESTIONNAIRE

HUMAN PERFORMANCE LAB **DEMOGRAPHIC QUESTIONNAIRE**

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way.

Section1: Driving History

Massachusetts drivers can have an unrestricted license, an intermediate (or junior operator's license) or a learner's permit. What type of driver's license do you currently hold?

- | | | |
|---|------------------------------|-----------------------------|
| a) an unrestricted license for the U.S.? | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| b) an intermediate (junior operator) license for the U.S. | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| c) a learner's permit for Massachusetts | <input type="checkbox"/> Yes | <input type="checkbox"/> No |
| d) Commercial Driver's License (CDL) | <input type="checkbox"/> Yes | <input type="checkbox"/> No |

How long have you held your current driver's license or permit? _____ years _____ months

About how many miles did you drive in the past 12 months?

☐ Less than 5,000 ☐ 5,000 to 10,000 ☐ 10,001 to 15,000 ☐ More than 15,000

Does your license require you to wear glasses or contacts? ☐ Yes ☐ No

If you responded "Yes" to the above question,
are you wearing your glasses/contacts today? ☐ Yes ☐ No

Do you ever get motion sickness symptoms while driving or riding in a car? ☐ Yes ☐ No

(If you respond Yes to the above question, please bring it to the immediate attention of the experimenter.)

Have you participated in a study at this Lab in the past? ☐ Yes ☐ No

If so, how many times? _____

Section 2: Demographics

Gender: ☐ Male ☐ Female

APPENDIX C

SIMULATOR SICKNESS QUESTIONNAIRE

SIMULATOR SICKNESS QUESTIONNAIRE (SSQ)

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:

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**INFORMATION PROVIDED ON THIS QUESTIONNAIRE IS STRICTLY
CONFIDENTIAL.**

You can skip any questions you do not feel comfortable answering.

Participant ID: _____ Date: _____

THIS SECTION OF THE QUESTIONNAIRE IS COMPLETED BEFORE USING THE DRIVING SIMULATOR.

PRE-EXPOSURE BACKGROUND INFORMATION

1. How long has it been since your last exposure in a simulator? _____
days

How long has it been since your last flight in an aircraft? _____
days

How long has it been since your last voyage at sea? _____
days

How long has it been since your last exposure in a virtual environment? _ days

2. What other experience have you had recently in a device with unusual motion?

PRE-EXPOSURE PHYSIOLOGICAL STATUS INFORMATION

3. Are you in your usual state of fitness? (Circle one) YES NO

If not, please indicate the reason:

4. Have you been ill in the past week? (Circle one) YES NO

If "Yes", please indicate:

a) The nature of the illness (flu, cold, etc.):

b) Severity of the illness: Very _____ Very
Mild Severe

c) Length of illness: _____ Hours / Days

d) Major symptoms:

e) Are you fully recovered? YES NO

5. How much alcohol have you consumed during the past 24 hours?

_____ 12 oz. cans/bottles of beer _____ ounces wine _____ ounces hard liquor

6. Please indicate all medications you have used in the past 24 hours. If none, check the first line:

- | | |
|---------------------------------------|-------|
| a) NONE | _____ |
| b) Sedatives or tranquilizers | _____ |
| c) Aspirin, Tylenol, other analgesics | _____ |
| d) Antihistamines | _____ |
| e) Decongestants | _____ |

- f) Other (specify): _____
7. a) How many hours of sleep did you get last night? _____ hours
 b) Was this amount sufficient? (Circle one) YES NO
8. Please list any other comments regarding your present physical state which might affect your performance on our test.
-

BASELINE (PRE) EXPOSURE SYMPTOM CHECKLIST

Instructions: Please fill this out BEFORE you go into the virtual environment. Circle how much each symptom below is affecting you right now.

#	Symptom	Severity			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe

12.	Mental depression	None	Slight	Moderate	Severe
13.	“Fullness of the head”	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	*Vertigo	None	Slight	Moderate	Severe
17.	**Visual flashbacks	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	***Stomach awareness	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27.	Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations of movement, when not in the simulator, car, or aircraft.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

THIS SECTION OF THE QUESTIONNAIRE IS COMPLETED AFTER USING THE DRIVING SIMULATOR.

POST 00 MINUTES EXPOSURE SYMPTOMS CHECKLIST

Instructions: Circle how much each symptom below is affecting you right now.

#	Symptom	Severity			
		None	Slight	Moderate	Severe
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	“Fullness of the head”	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	*Vertigo	None	Slight	Moderate	Severe
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18.	Faintness	None	Slight	Moderate	Severe

19.	Aware of breathing	None	Slight	Moderate	Severe
20.	***Stomach awareness	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
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24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27.	Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations of movement, when not in the simulator, car or aircraft.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

POST-EXPOSURE INFORMATION

1. While in the virtual environment, did you get the feeling of motion (i.e., did you experience a compelling sensation of self-motion as though you were actually moving)? (*Circle one*)

YES NO SOMEWHAT

2. On a scale of 1 (POOR) to 10 (EXCELLENT) rate your performance in the virtual environment: _____

3. a. Did any unusual events occur during your exposure? (*Circle one*) YES NO
b. If YES, please describe:

APPENDIX D

EYE TRACKER VIDEOS SCORING GUIDELINES

1. **Truck** - Glances between where the warning sign becomes legible and the actual warning: L
2. **Bus** - Glances between where the warning sign becomes legible and the actual warning: L
3. **Truck** - Glances between where the warning sign becomes legible and the actual warning: R
4. **Bus** - Glances between where the warning sign becomes legible and the actual warning: R
5. **Truck** - Glances at the actual warning sign
6. **Bus** - Glances at the actual warning sign
7. **Truck** - Glances between warning sign and SD: L
8. **Bus** - Glances between warning sign and SD: L
9. **Truck** - Glances between warning sign and SD: R
10. **Bus** - Glances between warning sign and SD: R
11. **Truck** - Glances between SD and tracks: L
12. **Bus** - Glances between SD and tracks: L
13. **Truck** - Glances between SD and tracks: R
14. **Bus** - Glances between SD and tracks: R
15. **Truck** - Glances after the truck in front has moved: L
16. **Bus** - Glances after the bus in front has moved: L
17. **Truck** - Glances after the truck in front has moved: R
18. **Bus** - Glances after the bus in front has moved: R
19. **Truck** - Glances at the actual lights: L
20. **Bus** - Glances at the actual lights: L
21. **Truck** - Glances at the actual lights: R
22. **Bus** - Glances at the actual lights: R

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