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UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

A VALIDATION OF VISUAL IMPENDING COLLISION WARNINGS FOR DRIVERS HEADING STRAIGHT THROUGH A SIGNALIZED INTERSECTION

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By

RYAN CHARLES STANLEY RYGIEL
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A VALIDATION OF VISUAL IMPENDING COLLISION WARNINGS FOR DRIVERS HEADING STRAIGHT THROUGH A SIGNALIZED INTERSECTION

A THESIS APPROVED FOR THE
SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING

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To my parents, Charles and Dr. Barbara Rygiel, my sincere gratitude for pushing me to strive for something great and continuing to push me to achieve it. Whenever I felt like I had failed or I wanted to give up, you were there to give me that little nudge I needed to get to the next step. This thesis has been a long arduous task, but I'm glad you were there to help me through to the end. Your guidance in life has made me who I am and there is no amount of words/action I can show that will ever convey my full gratitude for all that you have done.

When I originally came into the Industrial Engineering program at the University of Oklahoma, I had a pretty good idea of what I wanted to accomplish. My initial goal was to take what I learned in the IE courses and apply it to the world of sports. Entering my final year of my Bachelors Degree, I knew I wanted to pursue a Masters Degree with a focus in Human Factors and Ergonomics, hopefully writing my thesis on a baseball related topic. I worked with Dr. Randa Shehab on the biomechanics of baseball and began the thesis process during my final year as an Undergraduate. Upon returning for my final year at OU, I was informed the biomechanics work I had done was for not as the system I needed had gone down and the damage was irreparable. Dr. Shehab worked closely with me to find a new topic in a related field, which led me to this thesis. It's been a long road with many gaps, but we finally got here and I have her to thank for helping me through the long journey.

Dr. Chen Ling, you opened my eyes to a world of statistics I never knew existed and one that I still frequently visit (for vastly different reasons now though). Many of your courses through my degree path were key in deciding to continue on to a Graduate degree.

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Ryan Rygiel, Masters of Science in Industrial and Systems Engineering

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Abstract

Approximately 4% of all fatal crashes in the United States (1,092) occurred in cross path collisions at signalized intersections (NHTSA, 2011). This type of crash is especially dangerous as the victim driver is often oblivious to the impending collision. With the invention of a new traffic monitoring system WICAS (King et al., 2007), a proposed system to warn victim drivers of these crashes was studied. Novel out-of-car signals were designed using best practices in traffic signal design for reaction time and using some form of a familiar traffic sign/signal currently in use. A survey was conducted to determine the signals' validity of use in a simulation study. The survey found that drivers were inclined to stop at the signals even when their implied meaning was not conveyed. Once the signals were approved, a simulation was performed using the STISIM driving simulator to test driver reaction time based on signal type and light onset distance. Three signal types were used in the study: a regular progression signal, a novel "Do Not Enter" traffic signal, and a novel Growing traffic signal at onset distances of 250 and 300 feet. A repeated-measures two-way ANOVA found a significant difference in reaction times based on the interaction between signal and light onset distance. Both novel signals provided faster reaction times to the warning regardless of the onset distance. Thus, the use of either of the proposed novel signals would give the victim driver additional time to stop and assess the situation.

Introduction

Approximately 8% (or 2,283 of 29,372) of fatal crashes in the United States in 2011 occurred at signalized intersections. This percentage has been fairly consistent over the last 10 years of available data, ranging between 7-8% from 2000-2011. Of the 2,283 fatal crashes at signalized intersections in 2011, 48% (1,092 crashes) were cross path collisions (NHTSA, 2011). In this study, a cross path collision is defined as a right angle, or near right angle, collision of one vehicle into another vehicle, depicted in Figure 1 (U.S. Department of Transportation, 2003). This is also commonly referred to as a "T-bone" or front-to-side collision.

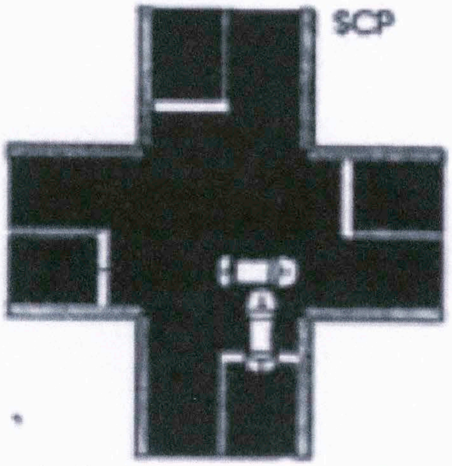


Figure 1: Cross Path Collision Diagram

Cross path collisions are dangerous as the victim driver is often oblivious to the impending collision from the violating vehicle. In the case of a red light running cross path collision, the violating driver is disobeying the posted signal (solid red – indicating stop) and the victim driver is obeying their posted signal (solid green – indicating the right of way). The violating driver may be disobeying the posted signal purposefully or accidentally, but in either case, the victim driver who is obeying the posted signals is still involved in a collision that may cost him/her their life. Previous studies have experimented with different ways of warning or deterring the violating driver from running the red light. While many of these studies have found valuable solutions to decrease the number of red light runners, there are still too many red light running collisions each year.

With the implementation of traffic sensors capable of tracking speed and distance from an intersection of approaching vehicles (King, Barnes, Refai, & Fagan, 2007), it is possible to develop a warning system for the potential victim drivers of a red light running cross path collision. The Wireless Intersection Collision Avoidance System (WICAS) was created to monitor intersections at busy highways. Using sensors, the intersection can be monitored for probable collisions and trigger a warning to the would-be victim drivers that there is a probable (or certain) collision if they enter the intersection. Applying this same technology to signalized intersections could also benefit victim drivers in those circumstances. Warning the would-be-victim driver would allow them to stop prior to the intersection to avoid the impending cross path collision, escaping injury or death.

Problem Statement

Previous studies focused on preventing red light violations by giving the violating motorist more information to make a safe decision. While most endeavors resulted in positive gains toward reducing red light running, some drivers continued to disobey posted signals. It's possible these drivers were distracted and missed the signal or that they were deliberately disobeying the signal. Since controlling the behavior of the violating driver is not fully effective, the best alternative is to warn the potential victim driver of the danger so that he/she can respond accordingly.

In order to reduce cross path red light running accidents, a speed and distance tracking system is in development to predict when a vehicle will run a red light. The Wireless Intersection Collision Avoidance System (WICAS) is designed to track each approaching vehicle's speed and distance from the intersection (King et al, 2007). If the system senses a vehicle is approaching and unable to stop, it will trigger a warning (a flashing beacon) for the would-be victim driver to allow them to stop safely before the collision occurs. If the system were altered for use at a signalized intersection, research is needed to determine how to communicate the collision warning information.

This study investigated a novel, out-of-car warning system to warn the potential victim drivers of the impending collision using a modified version of existing traffic signals. These signals would be triggered by the tracking system when it detects a violating vehicle. The goal of the study is to determine if the novel signals convey the "stop prior to the intersection" message to victim drivers and do so more quickly than traditional intersection signals.

Literature Review

Red Light Running Reduction

There have been many attempts in the past decade to determine why drivers run red lights and what can be done to deter them from doing so. Newton, Mussa, Sadalla, Burns, & Matthias (1997) designed and experimented with a new signal-phasing program for the state of Arizona called Traffic Light Change Anticipation System (TLCAS). This new system utilized a flashing amber signal between the solid green and solid amber phases to warn drivers of the impending solid amber and solid red signals. The thought was the addition of the flashing amber would give motorists more information and allow them to make a more informed decision on continuing through or stopping at the intersection. TLCAS was modeled after signal change anticipation systems in Israel that employ a flashing green signal and have produced a variety of results. Newton et al. (1997) based their experiment on the theory that increased time and information would reduce "dilemma" situations, or situations where drivers can neither safely stop nor safely cross an intersection.

The results showed that the new system was capable of reducing the number of red light violators, but with the consequence of making driver behavior more unpredictable for other drivers. The authors attributed this to a transformation of all the "dilemma" situations into "option" situations, where a driver could choose to either safely stop or safely cross an intersection. The increase in option situations created an issue for successive drivers as the preceding drivers' decisions to either stop or cross were in no way communicated to the successive driver. There was also greater uncertainty as to when the drivers would make their decisions, which also increased the probability of conflicting behavior from successive drivers. This study did provide the insight that additional information and time can improve driver decisions on stopping or proceeding through an intersection, however the increased timing also shifts many situations from the dilemma state to the option state translating risk to the succeeding drivers. While the addition of the flashing amber signal led to decreased red light running, it simultaneously creates a dangerous environment for drivers behind the driver in the option situation.

In 2002, Retting et al. took at different approach. They theorized that retiming the existing solid amber light interval for a signalized intersection could reduce the number of red light running occurrences. This proposition rested on the recommendation from The Manual on Uniform Traffic Control Devices (MUTCD) that all amber change intervals range between 3 to 6 seconds depending on approach speed ("Traffic Safety Facts", 2009). When this recommendation was combined with equations from the Institute of Transportation Engineers, the researchers could determine the optimal change interval based on level of pedestrian traffic expected at the intersection. The use of these equations allowed the researchers to optimize change intervals at 40 experimental sites and measure the effectiveness of the improved timing. The optimized amber signal lengths resulted in safer intersections with an 8% reduction in all reportable crashes and a 5% reduction in multi-vehicle crashes. However, these improvements were not significantly different from sites with non-optimal amber signal timing nor did they significantly reduce cross path collisions at experimental sites (Retting, Janella, & Williams, 2002).

In a follow up study in 2008, Retting and others coupled the amber change interval increase with the addition of red light cameras as an enforcement approach (Retting, Ferguson, & Farmer, 2008). The study consisted of 6 experimental sites located at troublesome intersections in Philadelphia. The changes were phased-in by first collecting baseline data, then implementing the retimed amber signal and collecting new data, and finally implementing the red light camera systems and collecting more data. The 6 experimental sites were compared to 3 comparison sites that had no changes made during the three phases.

The results indicated that while lengthening the amber change interval reduced red light running incidents, the more beneficial addition was the red light camera. After installation of the cameras, the percentage decrease in red light running violations ranged from 87% – 100%. The researchers concluded that while "providing motorists with adequate yellow signal timing is important for reducing red light running…even with proper timing in place, red light running remains a problem that can be further reduced through the use of camera enforcement" (Retting et al., 2008, p. 332). The addition of red light cameras was shown to further reduce the likelihood of a red light running violation and keep the majority of the population in compliance with posted traffic signals. The authors noted that although camera enforcement reduces cross path collisions, it may have the negative side effect of increasing rear-end collisions. However, since rear-end crashes are often far less severe than cross path collisions, research for camera enforcement has always shown a positive benefit.

Providing Warnings to Drivers

Signal timing and the addition of cameras are both out-of-vehicle tactics used to improve awareness and compliance with posted signals. Another option is in-vehicle devices. An in-vehicle device resides within the confines of the vehicle and gives an auditory, visual, tactile, or redundant (multiple modes) warning. Malts and Shinar (2004) conducted a study on the effectiveness of in-vehicle warning systems in aiding drivers to maintain sufficient headway distance from the car in front of them. Drivers completed the experiment using a driving simulator with an in-vehicle warning system for headway. Subjects were part of either the control group (no signal), or one of three groups (visual, auditory, or multimodal signals) that was provided a warning if the headway to the vehicle in front of them was less than 2 seconds. The results showed that the warning system, regardless of the modality, decreased the percentage of time spent within the 2-second headway from 12% to 7%.

While the previous study showed significant improvement during a relatively low demand mental workload driving task, Martens and Winsum (1997) tested several driving tasks through various levels of mental workload. They used the Peripheral Detection Task (PDT) to measure the workload of driver support systems in various driving scenarios. To achieve this, a small red square would appear in the driver's periphery and the driver would respond by pressing a microswitch with their dominant hand. A reaction time of longer than 2 seconds was considered a missed signal. The authors assumed that a higher percentage of missed signals or overall higher reaction times were indicative of higher workload.

The study found that as a driver approaches an intersection, their mental workload increases greatly, especially if they are required to come to a complete stop. This increased workload was shown as both an increased reaction time to signals and a higher percentage of missed signals for higher workload scenarios. The experiment also found that speech warning messages from an in-vehicle system severely increase the participant's mental workload as measured by the PDT. Overall, the study determined that an increased workload resulted in "cognitive tunneling", a state where drivers' "selectivity of attention increases with workload" (Martens and Winsum, 1997, pg. 6). These findings suggest that warnings/information may be missed/ignored at intersections or with speech-based messages as the increased workload induces "cognitive tunneling" for the driver.

In-vehicle solutions rely on a specific level of technology in the car and there is no way to ensure every vehicle on the road has the required equipment. An out-of-vehicle system is independent of the technology in the vehicle and can support the wide variety of vehicles on the road. An out-of-vehicle warning system also uses warning systems familiar to all drivers, such as the signs and signals followed during every day driving. Out-of-vehicle signals are appropriate for the collision warning system proposed in this study. This type of signal allows the traffic sensors to be directly connected to the current traffic signals and can take advantage of signals and placement with which motorists already have familiarity. Using the existing traffic light system would place the warning information in the location in which drivers are already accustomed to looking for information when approaching an intersection. The benefits are available to all drivers when the system is installed, rather than having a secondary requirement of a vehicle being equipped with the in-vehicle system.

With the choice of an out-of-vehicle system, an important question becomes the design of the signal(s) to convey the correct meaning to motorists approaching a dangerous intersection. In a study from Kurniawan and Zaphiris (2001) it was found that pictorial signs were more effective at relaying information quickly. Using a card sorting task and a questionnaire, participants from young and old age groups were asked to determine which version of a sign they preferred, pictorial or verbal. The study found that younger drivers preferred and were less likely to violate the pictorial signs. The reasons they chose the pictorial signs included "less reading", "familiarity", and redundancy in characteristics of the sign (i.e., symbol and color). The older population also preferred the pictorial signs but the difference wasn't significant.

Signals mean nothing if the intended targets cannot interpret them correctly. To aid in conveying the meaning of signals, Gros, Greenhouse, and Cohn (2005) found that a moving target or signal decreased the misses and improved identification. They referenced several other authors (including Gros et al., 1996, Watson et al., 1983 and Kelly 1979) that found similar results in related research. In particular, it was noted that there are two major human visual systems utilized for visual detection. The "M" system is utilized for motion detection and is the faster of the two systems but with less sharpness. The "P" system is used to detect colors and more refined vision but is much slower to perceive the object. Since the "M" system is faster to detect stimuli, using a flashing signal should decrease the visual reaction time needed for the motorist to perceive the signal.

Simulation Studies

Utilizing simulation studies provides a safer and more controllable environment for researchers conducting traffic studies; however the validity of driver performance in simulator studies has been scrutinized. A study performed by Allen et al. (2004) aimed to determine how traffic simulation technology faired with the accuracy vs. speed paradigm (recognition/response time vs. correctness) of normal driving. The study found that driver performance in traffic simulations degrades as the signs/signals become more complex. It was also found that prohibitive signals (red light, stop sign, etc.) resulted in the best performance during the simulation. However, the best performance may be better than a driver’s normal behavior. Maltz and Shinar (2004) concluded that using a simulator could elicit a driver’s best behavior rather than their typical driving conduct. Thus, some question the ability of simulator studies to result in useful data to predict actual driver behavior. However, due to the flexibility, safety, and lower cost, simulator studies are used to measure and predict typical behavior.

Survey Study

This study introduced novel signals to drivers in an effort to create a warning system to warn drivers of impending cross path collisions. The goal for the study was to determine a novel signal that would warn victim drivers of a cross path red light running collision and test it against a regular progression signal in a simulation study. Prior to running a simulation study, the novel signals needed to be created and tested for the validity of the inferred message. A survey was conducted to determine the perceived meaning of the novel traffic signals and whether they would be usable in a simulated driving environment.

Subjects

Study participants were volunteers from the student population at the University of Oklahoma. All participants were required to have a valid U.S. driver's license and corrected vision if specified on their driver's license. Twenty-two subjects provided informed consent to participate in the survey portion of the study; 13 were male and 9 were female.

Apparatus

The survey was displayed via PowerPoint on a MacBook computer (connected to an overhead projector) and responses were recorded on paper.

Experimental Design

A survey was created via PowerPoint with 21 slides to present participants with signs and signals they might encounter during every day driving. These signs and signals included “Do Not Enter”, “Pedestrian Crossing”, “Red-Light”, and other signals depicted in the MUTCD. Currently existing signs/signals accounted for 19 of the 21 total slides presented in the survey. The other two slides contained two novel signals: a growing red light that progressed from one-third of its diameter to its full diameter in three steps (Figure 2); and a flashing do not enter signal (white bar across the red light; Figure 3). These novel signals are prohibitive and both are derivatives of existing signs/signals with a flashing component to aid in capturing motorists’ attention more quickly. They were designed in such a way that only minor edits to an existing traffic light would be necessary to keep the warning in the same location as drivers are already conditioned to look for information while driving. The added benefit is that the novel signals would not interfere with the look/position of an existing traffic signal.

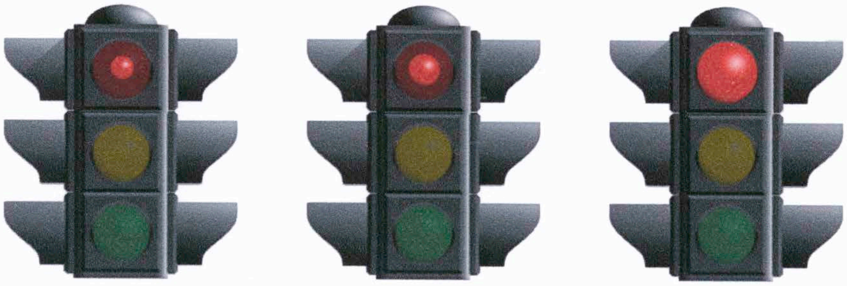


Figure 2: Growing Light

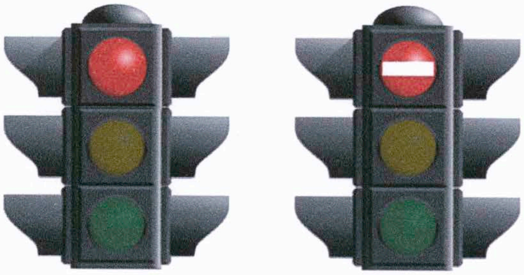


Figure 3: Do Not Enter Light

The first slide of the presentation displayed the requirements of the study and reminded the participants of the opportunity to opt-out prior to beginning the study. Signals were then presented as either stationary PNG images (if solid state) or animated GIF images (if flashing). If the signals were flashing, a 60 Hz flash rate was used to be consistent with the recommended values in the MUTCD (2009). The distracter signals were ordered randomly, with the novel signals holding the 8th and 17th positions.

An answer sheet was given to each participant with spaces for the participant to indicate their understanding of the meaning of the presented signal and the appropriate "driver response" for the signal. The answers to the questions were free response without prompting. Allowing free response provided insight into what information the presented signal conveyed to the participant, both in cognitive understanding and in what their response would be if they encountered the signal while driving. The survey was used as validation drivers were capable of interpreting current MUTCD signals and the meanings of the novel signals were interpreted correctly.

Each participant took the same twenty-one-question survey, and was allowed to take the survey individually or in a group. When the survey was given in a group setting, participants were not allowed to discuss survey answers and signals until the survey was fully completed and answer sheets were turned in. Consent and testing for the study took place in a converted office that was separated from the general population. This room included 3 desks, 1 of which was used by the experimenter for setup and 2 desks moved together with several chairs for participants to sit in a group.

Procedure

Upon arrival, participants were given information on the survey study. They were required to sign an informed consent form and present a valid U.S. driver's license in order to participate. The license was required to prove that they had taken and passed a driving test in the U.S. indicating they were familiar with the rules and signage on U.S. roads. After informed consent was obtained, the participant began testing.

The participants (either individually or in a group) were taken into the survey viewing room and seated at a table. The presentation (Appendix A) was set in advance to the first slide, which presented the setup for the study and the rules the participants needed to abide by. When the survey was taken in a group setting, the experimenter reminded the group that discussion of the signals during the study was forbidden. Participants were given ample time to read the first slide and were asked if there were any questions prior to beginning. Prior to switching to slide two, the experimenter gave a reminder that participants could end participation at any time if they were uncomfortable or wanted to quit. Participants were given as much time as required to consider the meaning and how they might respond to each sign/signal before moving to the next signal.

Results and Analysis

A total of 22 subjects participated in the survey study providing their interpretations of traffic signs/signals. The full results of the study are attached in Appendix B. For the purpose of this study, the answers were considered correct if the meaning and/or described response fell into the MUTCD guidelines for that sign/signal. Of these 19 standard signal questions, only one signal elicited incorrect responses for the meaning of the sign: yield ahead. However, for driving response, the yellow light had 11 participants (50%) respond incorrectly with "speed up into the intersection," despite their correct response to the actual meaning. The two slides with the novel signals yielded somewhat different results, as the "growing light" had no incorrect responses and the "do not enter light" had 5 incorrect responses.

Table 1: Survey Response Breakdown

Signal	**Incorrect Meaning**	**Incorrect Driving Response**
NOVEL SIGNALS		
Growing	0	0
Do Not Enter	4	4
STANDARD SIGNALS		
Yellow Light	0	11
Yield Ahead	1	1
All Others	0	0

For the "growing light", many participants indicated it resembled a flashing red light and it signaled them to stop at the intersection. This is not to say the driving reactions were wholly accurate, as one participant noted they would "slam on the brakes". This reaction was not common, as most indicated they would brake and treat the intersection as a stop sign or flashing red signal. In fact, several participants noted they originally deciphered the signal as a flashing red. All 22 participants indicated they would stop at the light/intersection if they encountered it while driving.

The "do not enter light" had 4 incorrect responses: 2 indicating "yield" and 2 without an answer. While there was no consensus meaning of the signal among the subjects, the actions taken by 18 participants (82%) indicated they would stop at the light/intersection. Five of 22 participants, or 23%, described the signal as "broken" or "malfunctioning". The notion to stop at an unfamiliar signal seems like a reasonable expectation to most drivers, so the novelty of the designs may have played a role in the participants driving response. Although the intended meaning was not understood in all cases (4 with growing, 8 with "do not enter"), the majority of participants indicated they would stop if encountering the novel signals. Since the majority of drivers did indicate the correct meaning and the correct response, the researchers felt the signals were adequate to move forward into a simulation study.

Simulation Study

After the survey study showed the signals' meanings and intended actions were fairly well understood, the researchers moved to the simulation portion of the study. The novel signals were used in a driving simulation to determine if the survey study results translated to actual driving behavior.

Subjects

Study participants were volunteers from the student population at the University of Oklahoma. All participants were required to have a valid U.S. driver's license and corrected vision if specified on their driver's license. Sixteen subjects participated in the simulated driving portion of the study, 9 were male and 7 were female. Ages of participants ranged from 19-45 years of age with driving experience ranging from 2 to 20+ years.

Apparatus

Testing involved running STISIM Drive driving simulation software (Figure 4) version 2.08.04 provided by Systems Technology, Inc. (Hawthorne, CA). The computer used for the simulation task was a Dell Vostro 410 connected to two Dell LCD flat screen monitors for the researcher and a projector display providing the visual display of the driving simulation. The simulator setup consisted of the projector display positioned so the projected image was positioned such that the driver would feel as though they were sitting in a vehicle looking out the front windshield. The participants were seated in a bucket style automobile seat, capable of moving forward and back to accommodate individual heights and preferences. The controls were a Logitech G27 steering wheel with turn signal knob, and gas, brake, and clutch pedals (Note the turn signals and clutch pedal were not needed in this study). The steering wheel was capable of 900-degree wheel rotation, which allowed the driver to go 2.5 times around lock-to-lock, similar to that of real consumer vehicles.

Figure 4: STISIM Drive simulation screenshot

Another consideration in using a simulation was how to create a more realistic driving experience for the participant using the simulator. In order to keep participants engaged in the driving task, a secondary task was added to the primary task of driving. The goal of the secondary task was not to distract the driver, but to simply keep their attention on the simulated driving task for the duration of the study. The secondary task was designed to mimic driver scanning of the environment while not consuming excessive spatial resources. Gathering vehicle color is in line with normal driving behavior (e.g., scanning the surroundings) and has been used in a different study as one of the "driving tasks" participants complete during a simulated drive (Zheng, 2005).

Experimental Design

The simulator portion of the study employed a 2 x 3 within-subjects repeated measures design. As a participant moved through the simulation, they approached multiple traffic signals. Some of these signals remained green and signaled the participant to continue through. Other traffic signals actively changed when the participant reached a specific distance from the intersection (i.e., the onset distance): either 250 ft or 300 ft. These were selected considering the posted speed limit of 55 mph to give the drivers either a 3-second lead time (i.e., 250 ft) or a 4-second lead time (i.e., 300 ft) prior to the intersection. The 3 and 4 second lead-times fall in line with the MUTCD (2009) recommendations for yellow signal timing.

At these "active" traffic lights, one of three signals was displayed to the participant each using a vertical stoplight with either 1) a normal progression of green-amber-red, 2) a novel growing red light, or 3) a novel flashing "do not enter" signal. The regular progression was used as a control signal to determine the drivers' normal behavior when approaching an intersection and encountering an amber or red light. The latter two signals (growing and do not enter) were the novel signals designed for this study. Each participant was randomly assigned to one of two groups balanced around the order of the novel signals throughout the simulation. The order of the intersections was fixed, but the order of the novel signals was reversed between the two groups (i.e. when one group saw a growing light, the second saw a "do not enter" signal).

Each group experienced the same number of novel signals (two at each onset distance, yielding four total for each signal type) and the same number of control regular progressing stoplights (three at each onset distance, six total). There were also several intersections with continuous green lights. These intersections were to keep the participants from expecting a light change and braking in anticipation prior to the signal change. Figure 5 depicts the pattern of active signals throughout the simulation. Where "Signal 2/3" is designated, the participant experienced one of the novel signals based on which balanced group they were in. The "@#####" indicates the distance (in feet) into the simulation run the driver would experience these signals.

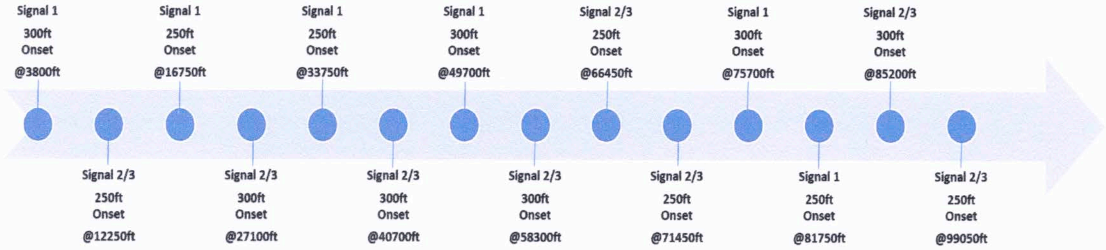


Figure 5: Simulation Study Timeline

Procedure

Consent and testing for the study took place in a converted office that was separated from the general population. This room included 3 desks, 2 of which were for the researcher and 1 was used for the experimental setup. Consent occurred at the experimental setup desk, and consisted of reading and signing the informed consent form. A valid U.S. driver's license was required to prove that they had taken and passed a driving test in the U.S. indicating they were familiar with the rules and signage on U.S. roads. After informed consent and proof of licensing was obtained, the participant could begin testing.

Participants were provided the driving simulator study instructions (Appendix C) to review and ask questions. The subjects were not informed that the study included novel signals to ensure their initial reactions to the signals were captured. Once all questions were satisfied, the participant was led to the driving area and allowed to adjust the seat to fit their preference. The participant was then given a practice run to familiarize themselves with the vehicle controls while driving in the simulator. The 5-minute practice run exposed drivers to a rural road with a few regular progression signals to get comfortable with control of the simulated vehicle. While driving, subjects were also tasked with calling out the colors of passing vehicles on the road (e.g., blue, red, yellow, or police) to impose a minor distraction to keep them from focusing on upcoming signals. Once the practice run was completed, the participant was given the option to start the test run or to perform the practice run again if they were still not comfortable with the controls and needed more practice.

Prior to starting the test run, the participants were given one last opportunity to ask questions and review the instructions to ensure they understood the task. They were also reminded that they could opt-out for any reason should they feel the need. The experimenter then started the actual simulation, which took subjects about 40 minutes to complete. During the simulation, the subjects were tasked with driving a two-lane road and maintaining a speed of 55 mph. They were informed they should obey all posted signs/signals and maintain position in the left lane of the two-lane road while remembering to call out the opposing lanes vehicle colors as encountered. The experimenter recorded the colors called out to verify participants were attending to the passing cars.

During the simulation, the drivers encountered four different signals at the intersections: 1) a typical continuous green light, 2) a typical signal light with a regular progression to red, 3) a novel growing red signal, and 4) a novel "do not enter" red signal. Most of these signals were "false alarms" in that no vehicle was crossing the participant's path. However, there was one intersection toward the end of the study that used a novel signal while exposing the driver to a potential cross path collision. The expectation was that participants would see and interpret the signal as they had previously done, and then see the car speeding through the intersection as they came to a stop. This was not employed at each test intersection, as the situation isn't likely to arise that often in each person's driving experience. Thus, having several "real life" instances in a small time frame was not a realistic experience for the participants. Subjects were also required to identify the color of each of the 60 vehicles passed in the simulation. The oncoming vehicles were placed in the same order for each participant and their responses were recorded to ensure they weren't just focusing on the signalized intersections in the simulation.

As subjects drove the vehicle, STISIM recorded the time, speed, distance, brake input value, acceleration, and lane-position every 1/30th of a second. This increment, 1/30th of a second, was the smallest amount of time that could be used to log the data without experiencing lag due to constant CPU usage from data writing. The data captured were used to determine the subjects' reaction times to the signals, the totality of the brake depression, and to ensure they were following the instructions regarding speed and lane position. The reaction time was defined as the time elapsed from signal onset to an intentional brake depression. The STISIM data recorded breaking in the range of 0 (fully engaged) to 65,535 (fully released), and an intentional brake was considered a 1/4th depression or a value of 40,000.

The simulation lasted approximately 40 minutes, after which time the participants were given the debriefing sheet (Appendix D). After the participant read the sheet, the experimenter allowed time for the participant to ask any questions regarding the purpose of or experiences within the study. When all questions were satisfied, the participant was required to sign the debrief sheet, indicating that they had received it and giving their permission for their data to be used in the analysis of the study. At that point, the participant was led out of the room and the experimenter cleaned the simulation area for the next participant. The experimenter also created backups of the data created from each participant on an external hard drive, with the participant number as the only piece of identifying information.

Results and Analysis

After all the data were collected, the experimenter analyzed the distraction data log to determine if any of the participants had issues with the distraction task. No participant missed more than 2 color identifications (3.33%), which was considered trivial for this study. Such a low number of missed colors indicated that the task did not induce "cognitive tunneling". This means that the participants were able to complete the secondary task without much increasing mental workload, which was the goal of the task. Since all participants passed the secondary task, the experimenter began collating the data.

Upon analysis of the reaction time data, the experimenter noted some outliers within the initial data. Primarily, there were abnormally low reaction times to the first "active" signal encountered in the study. Every participant exhibited a significantly lower reaction time on the first signal than any other; mean reaction time for signal one across all participants was 0.318s with a standard deviation of 0.205s compared to 1.407s with a standard deviation of 0.296s at all other regular signals (Figure 6). Further examination of the data showed that the coefficient of variation for Signal 1 was 0.643 compared to 0.195, 0225, 0.288, 0.161, 0.162 for the other regular signals.

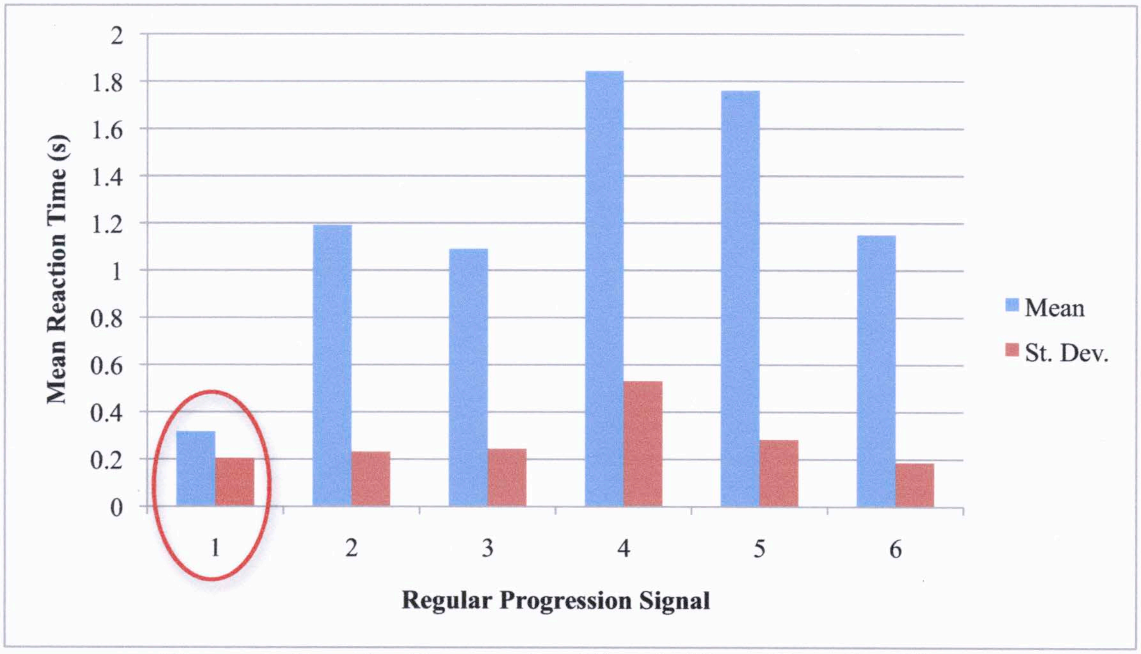


Figure 6: Regular Progression Signals Mean Reaction Time

The experimenter could not explain this behavior and could not find prior studies with similar findings. The experimenter believes it may have resulted from the participants anticipating a signal after the trial run and not providing their "normal behavior". All other signals exhibited reaction times more in line with standard rates. Since signal one exhibited a much lower mean and much higher coefficient of variation, the decision was made to exclude the initial signal from the data set.

Two participants also exhibited behavior that did not allow their data to be included in the study. Participants 6 and 8 both missed several signals and did not have enough data points for regular signals to qualify for inclusion. Each participant missed 4 of the 5 regular progression signals, leaving only one data point for those signals. Those misses also accounted for over half the total missed regular progression signals across all participants. With only one observation, there was not sufficient data for a within subjects analysis. In addition, these participants did not adhere to the experimental instructions to follow the posted traffic signs/signals as they never attempted to brake at any of the missed signals. Instead, these misses all involved the participant running through the intersection without depressing the brake at all. It is important to note these participants did not miss any novel signals during their simulation run; only regular progression signals were missed. However, the lack of protocol adherence led to Participants 6 and 8 being excluded from the final data analysis for this experiment.

Figure 7 depicts the remaining participants' mean reaction times to the three signal types. From the image, the visual representation appears to show a longer mean reaction time to signal 1 than to signals 2 or 3. In order to confirm this hypothesis based on the visual data, a two-way within subjects ANOVA was needed.

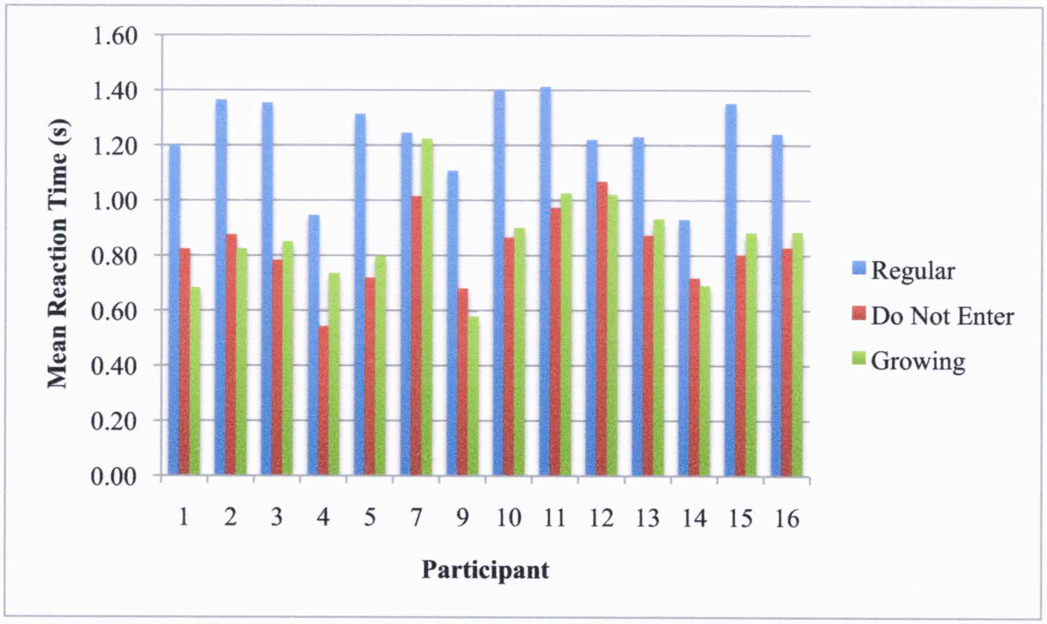


Figure 7: Average Reaction Time by Participant

One of the key factors in the study was capturing the reaction time to the first encounter with each novel signal to see if it differed from the regular progression signals and/or the following encounters with the same signal. Figures 8 and 9 depict total mean reaction time to the signal based on when the signal was encountered. The first encounter for each signal occurred at either Signal 2 or Signal 4 depending on the balanced group the participant was in. As shown, the first encounter with the signals yielded nearly equal reaction times as the later encounters with the signals.

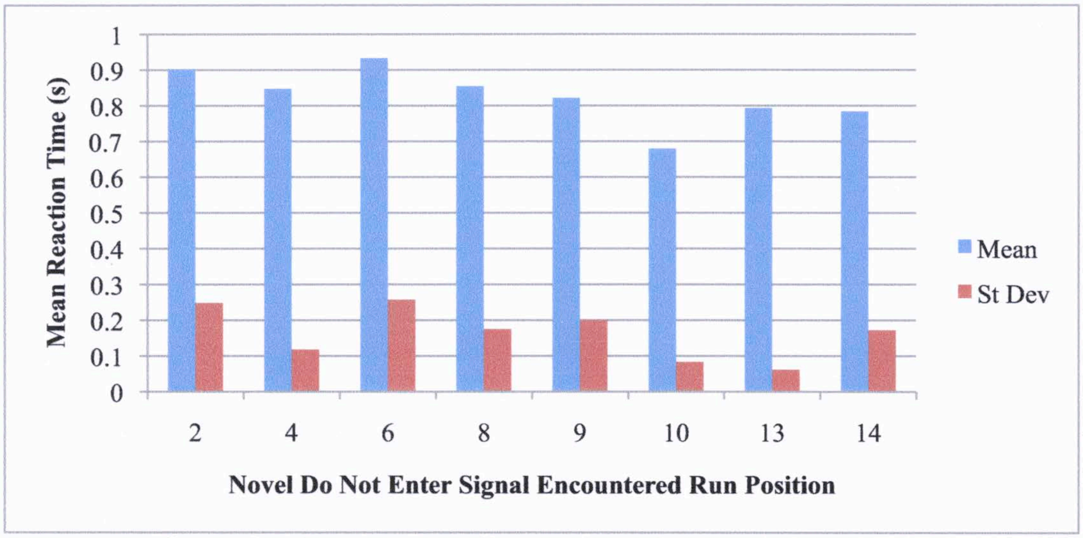


Figure 8: "Do Not Enter" Reaction Time by Signal Order

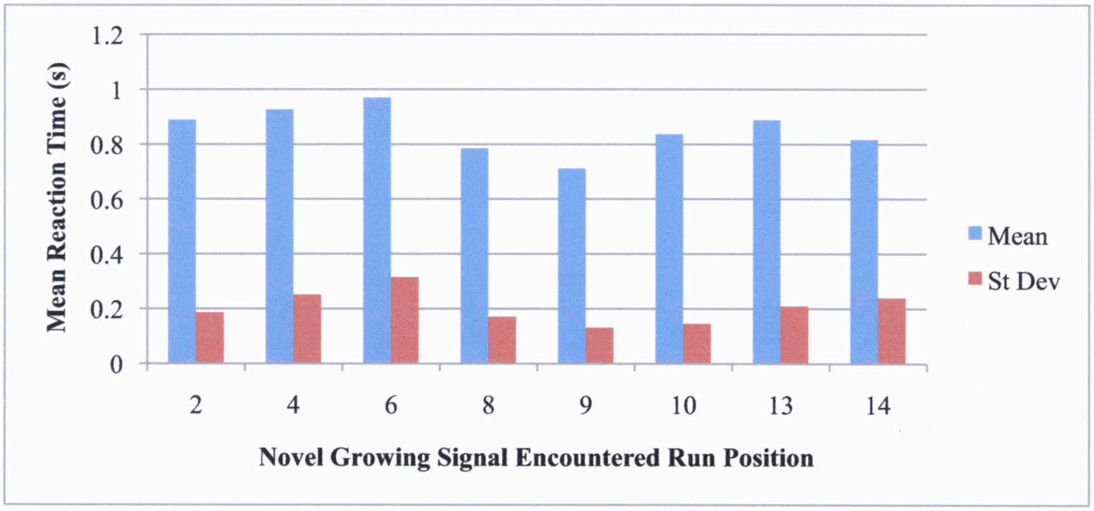


Figure 9: Growing Reaction Time by Signal Order

In order to get valid results from the ANOVA, the residuals were analyzed to verify the ANOVA assumptions. The first check performed was for the assumption of normality using a Shapiro-Wilk test for normality on the residuals from the data (Figure 10). The data trend in a fairly linear path and seem to stay within the bounds of a "normal" distribution. Since ANOVA is robust to non-normality, the abnormalities in the data aren't too concerning and the data were considered to follow a "normal" distribution.

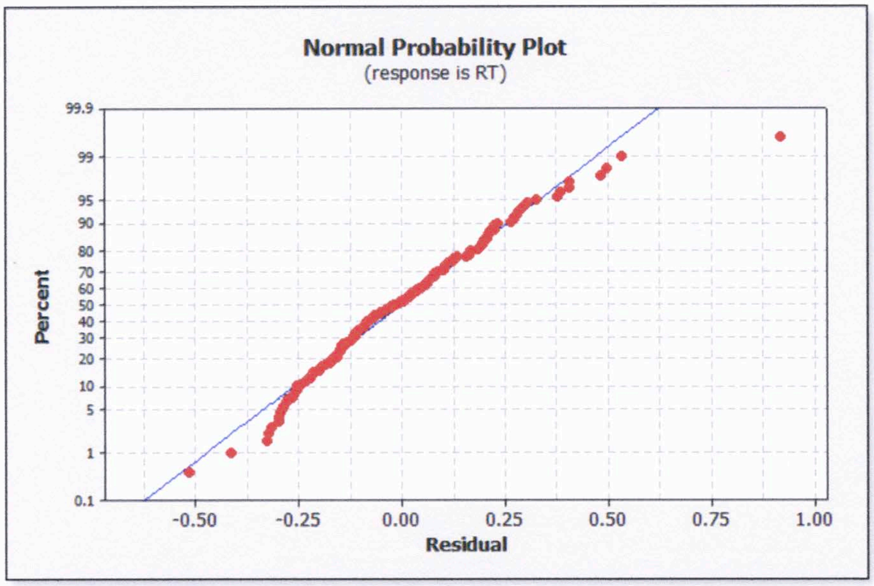


Figure 10: Normality Plot of Reaction Time Residuals

The next test was to determine if the assumption of equal variance across levels of the independent variables was valid. Equal variance was confirmed by plotting the residuals against the fitted values for reaction time and checking for any patterns in the data (Figure 11). While there was a slight trend for the lower values of the fitted variable to have a smaller spread among the residuals, most of the residuals appeared to have a fairly consistent range.

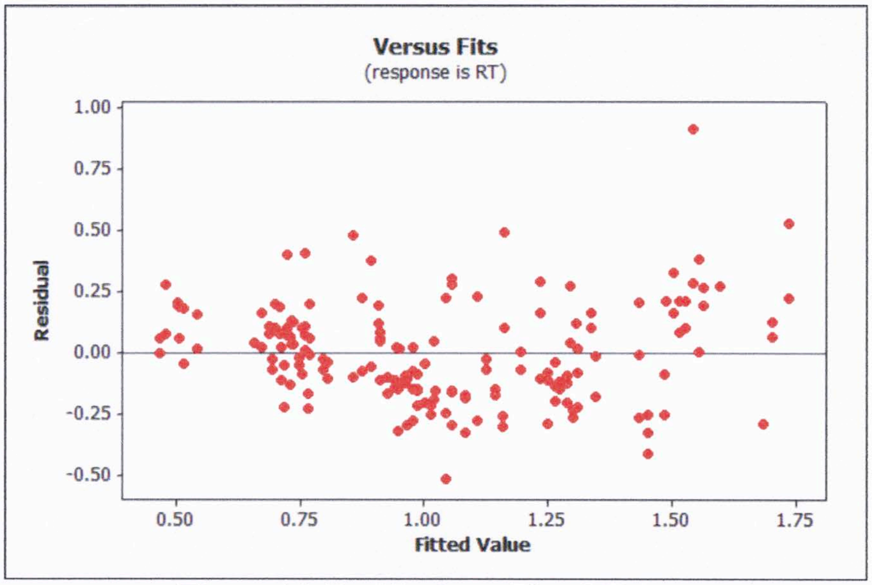


Figure 11: Residuals vs. Fitted Values

The final assumption reviewed was independence in order to examine for systematic bias in the order of testing. Figure 12 shows that the residuals have no clear pattern/organization in relation to order, indicating the data points are independent.

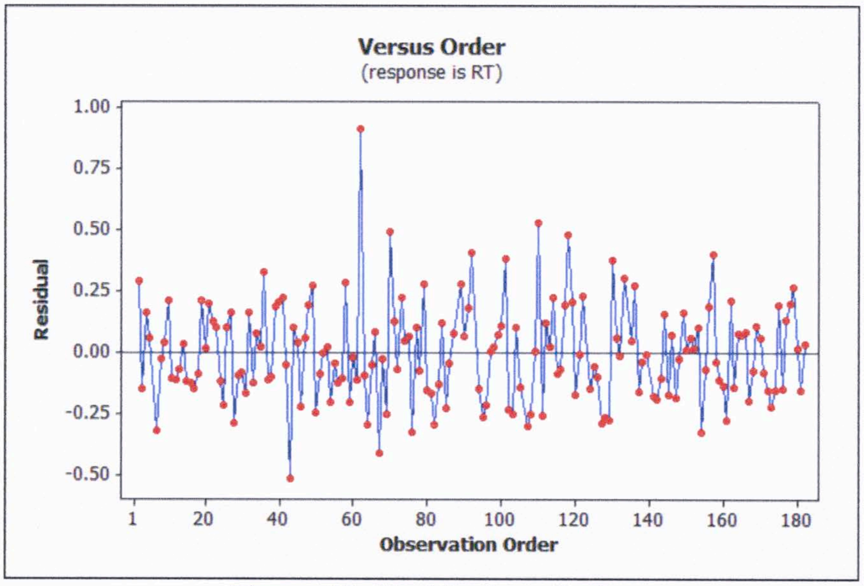
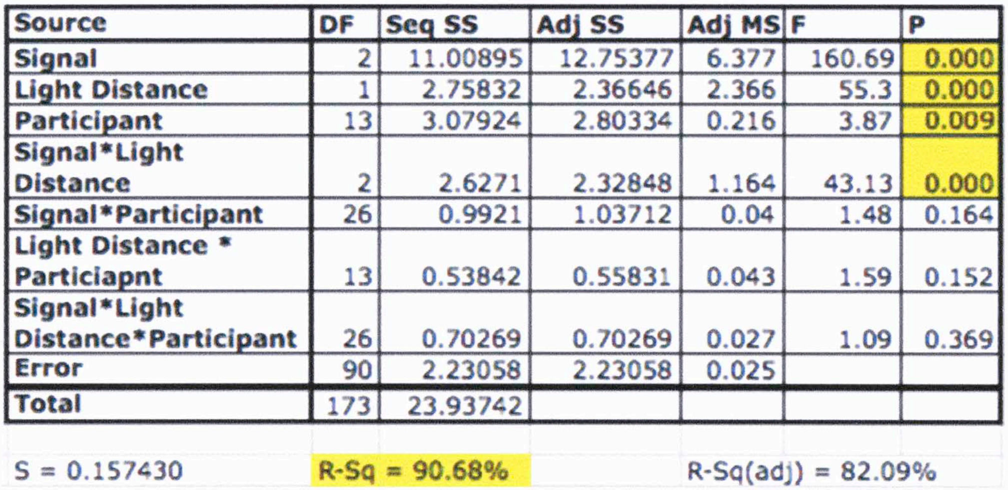


Figure 12: Residuals vs Order

Once all assumptions were satisfied, the data were analyzed using two-way within-subjects ANOVA (repeated measures design with signal and light onset distance as repeated factors) with α=0.05 (Table 2).

Table 2: ANOVA Table



Source	DF	Seq SS	Adj SS	Adj MS	F	P
Signal	2	11.00895	12.75377	6.377	160.69	0.000
Light Distance	1	2.75832	2.36646	2.366	55.3	0.000
Participant	13	3.07924	2.80334	0.216	3.87	0.009
Signal*Light Distance	2	2.6271	2.32848	1.164	43.13	0.000
Signal*Participant	26	0.9921	1.03712	0.04	1.48	0.164
Light Distance * Particiapnt	13	0.53842	0.55831	0.043	1.59	0.152
Signal*Light Distance*Participant	26	0.70269	0.70269	0.027	1.09	0.369
Error	90	2.23058	2.23058	0.025		
Total	173	23.93742				

S = 0.157430 R-Sq = 90.68% R-Sq(adj) = 82.09%

The interaction between signal and light distance was determined to be significant with a p-value of <0.05 indicating that the combined effect of signal and light onset distance plays a significant role in reaction time. The R-squared value of 90.68% indicates that approximately 90% of variation in reaction time in this study can be attributed to the factors included in this model. This indicates that the model is a good representation of the data, meaning the model is a good predictor of the actual data.

The interaction plot shows non-parallel tendencies for the signal/distance combination, indicating interaction. As shown in Figure 13, The regular progression signal has a higher reaction time than the novel signals across both of onset distances, with a much more dramatic difference for onset distance of 300 ft. This suggests that light onset distance may be a strong effect for the regular progression signal. However, the novel signals both show only the slightest increase in reaction time with the increase in light distance.

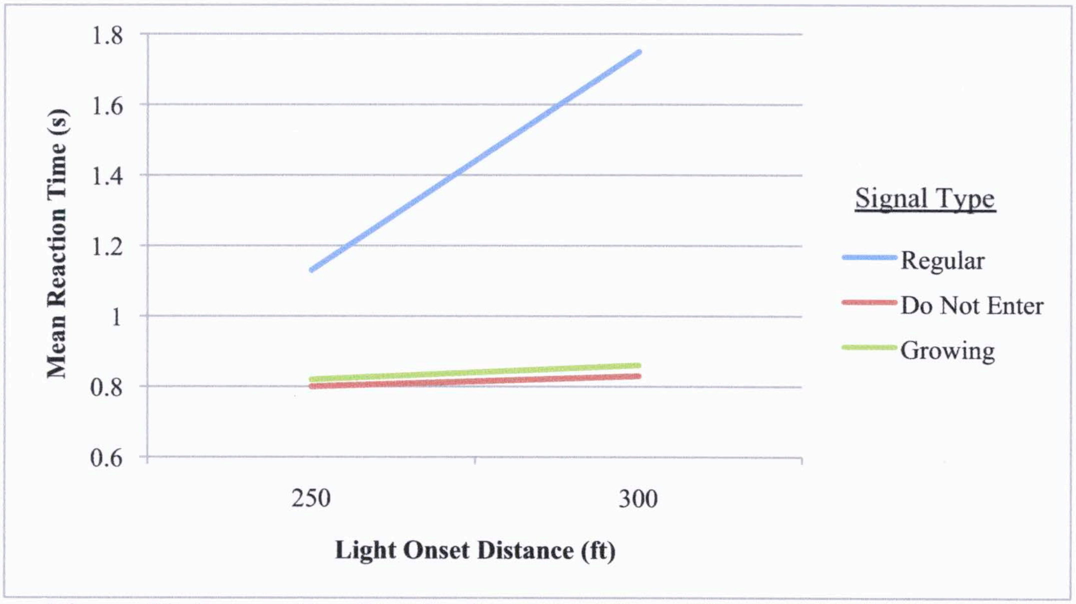


Figure 13: Interaction Plot for Reaction Time (Signal & Light Distance)

A Tukey HSD Test with a 95% confidence interval was performed to determine which levels of interaction were significantly different.

Table 3: Tukey HSD (95% CI) Results

Signal	Light Distance	N	Mean	Grouping		
1	300	24	1.7372	A		
1	250	39	1.1443		B	
3	300	28	0.8975			C
2	300	28	0.8564			C
3	250	28	0.8204			C
2	250	27	0.7932			C

Table 3 indicates that the regular progression signal at a light distance of 300 is significantly longer than the same signal at a light distance of 200. Both of the regular progression signal conditions were significantly longer in reaction time than the remaining combinations using the novel signals, of which all were not significantly different. . In sum, at either light distance, the regular progression signal exhibits a higher mean reaction time than any of the Signal 2 or 3 treatments novel signals. Light distance had no significant effect on mean reaction time for either of the novel signals.

Conclusion/Discussion

Cross path collisions are a prevalent form of fatality accidents in the United States, accounting for approximately 4% of all fatality crashes in 2011. These crashes are particularly dangerous as the victim driver has very little time to react. With the development of oncoming traffic speed/distance sensors, it is now possible to detect a red light runner when they reach the point of “no return”, the point where their speed and distance will not allow them to stop prior to the intersection. At this point, conveying the warning of the impending collision to the victim driver could allow them to stop prior to entering the intersection.

In this study, the experimenter created two novel traffic signals to convey the message to “do not enter the intersection” and provide a quicker reaction time than a normal signal progression. The survey study revealed that while the intended meaning of the signals is not always conveyed, the action to stop is. This may be partially attributed to the novelty of the signals and a natural human reaction to be cautious when encountering unknown signals/objects. When used in a simulation study, these novel signals, when combined with either light onset distance provided a significant reduction in reaction time for participants when compared to a regular progression signal at either light onset distance. The simulation data backed up the survey data that suggested the participants would react to the novel signals and stop prior to the intersection.

This study provides the initial confirmation that using one of the proposed novel warnings to inform a victim driver of a cross path collision can yield a significantly faster reaction time to stop the victim vehicle. This time could be the difference between the victim stopping short of the intersection or being involved in a cross path collision. The initial data appear promising in designing a warning system to detect, trigger, and inform of an impending red light running collision. However, there were some limitations to the study.

The study ran for approximately 40 minutes and the subjects encountered 4 of each novel signal. This is likely more frequent than a normal driver would encounter such signals if implemented in the real world. Thus, there may have been some conditioning to the signals or conditioning to the simulation as was reported in the literature review. One of the challenges of running and designing this experiment was the balance between the amount of data points collected for the novel signals vs. the number of times an individual might encounter the signal in everyday driving. To the average driver, cross-path collisions are rare so being exposed 4 times to each novel signal was likely "over exposure".

The experimental signals were also limited to only three levels; regular progression, "do not enter" and growing. However, using only these three levels does not allow for fully understanding the participant responses. If a flashing red signal had been used, it would have helped determine if the novelty of the signals caused the faster reaction time, or if the flashing design was mostly responsible. One issue with using this previously encountered signal is that the signal has a previously defined meaning and this application would create a secondary meaning, which could be confusing to drivers. This is a needed addition to future studies as a "new" signal might not be warranted if the flashing red light shows similar improvement in reducing reaction time without confusion of response.

Future Research

Participants in this study were “deceived” in that they were not made aware of the signals prior to the experiment. The first encounter they had with the signal was while driving in the simulation, which was a key piece for this study. In “real world” application, it’s likely the signal will be novel to drivers as the encounter rate should be low. However, if the signals are implemented, it’s likely they will become a known part of an individual’s driving education. A study on the long-term effects of these signals should be performed, in which the participants are either informed of the new signals or are “educated” on the meaning to determine if knowledge of the signal affects the reaction time to the signal.

To address the limitations of this study, a follow up study should be conducted using the same parameters and with a fourth signal type, flashing red. This should determine if the novelty of the signals or design of the signals was the largest contributing factor to the improvement in reaction time. Another study could examine the impact of the surrounding environment on driver behavior and driver response to novel signals. The simulation run in this study was mostly void of true surrounding traffic (except for the secondary task vehicles in the opposing direction). As the mental workload of the driving experience increases (due to approaching traffic in all directions) it is expected that “cognitive tunneling” would delay or prevent detection of warning signals.

If results from a long-duration simulation agree with the initial encounter data from this study, a move to a field study would be in order. It is argued that simulation studies do not provide “real world” data and instead provide the “best behavior”. If this is the case, then a field study would allow researchers to get the full picture on the impact of the novel warning system for drivers. The field study would be similar to the simulation in that the drivers should not be put in actual danger of a collision. It would also be informative to repeat the condition of two groups of participants, one with no prior knowledge of the signals and one exposed to the signals prior to driving. This could give further evidence in “real world” situations of the effectiveness of the novel signals in reducing reaction time.

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Appendix A: Survey PowerPoint

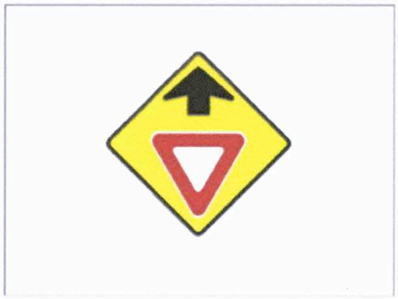
Traffic Warning Survey

Each of the following slides will present one traffic sign or signal.

Please use the response sheet provided to answer the following questions:

1)What does the sign or signal mean?
2)How would you respond to the signal if you were driving?

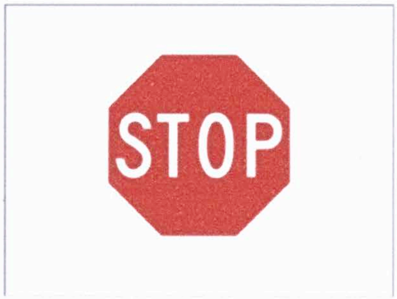
Remember, you can quit at any time
if you are uncomfortable or want to stop.



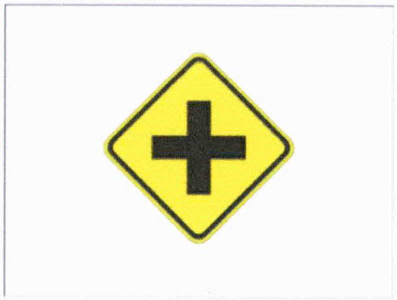

SLOW


YIELD

5/17/12




BE
PREPARED
TO STOP



Appendix B: Survey Results

	Question																				
	Red Light	Yield Ahead	Stop Light Ahead	No Right Turn	Watch for Bicycles	Slow Down	Pedestrian/School Crossing	*Growing Stop Light	Watch for Wildlife	Flashing Red	Yield	Pedestrian Crossing	Yellow Light	Stop Sign	Stop Ahead	No U-Turn	"Do Not Enter" Signal	No Left Turn	Flashing Yellow Light	Be Prepared to Stop	Intersection Ahead
Participant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
3	✓	x	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
5	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	x	✓	✓	✓	✓
8	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
9	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
11	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	x	✓	✓	✓	✓
12	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
14	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
15	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
16	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
17	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓	✓
18	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓
19	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	x	✓	✓	✓	✓
21	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓
22	✓	✓	✓	✓	✓	✓	✓	✓	✓	*✓	✓	✓	**✓	✓	✓	✓	✓	✓	✓	✓	✓

*Participant 22 deciphered the Growing Signal the same as a flashing red

**Yellow means speed up if close to the intersection (not good for a RLR situation)

	Growing Stop Light	"Do Not Enter" Stop Light
Participant	Q8 - Answer	Q17 - Answer
1	Stop here - treat as red light	Don't go this way - Go another way
2	Stop light, unsure - slowly stop	Broken light - Stop
3	4 way stop - stop at intersection to right of way	Stop - slow down and stop
4	stop light out - stop as if stop sign	Stop with white flash (Stop) - Stop
5	stop and look to go - stop at light and wait for right of way	Stop and take caution - come to a stop and look both ways
6	stop light out - stop as if stop sign	stop - stop car
7	treat as 4-way stop - stop and wait for right of way	Yield - treat as yield sign
8	stop - stop as normal red light	stop - stop temporarily at intersection
9	stop light out - stop as if stop sign	messed up signal - stop and look around
10	stop - stop	traffic signal on highway - stop/press brake
11	stop vehicle - treat as stop sign	? - ?
12	stop quickly - slam on break	Do not enter - don't enter intersection
13	stop - hit the breaks	Broken light - disregard and keep moving
14	stop - treat as stop sign	? - very confused then likely a wreck
15	stop - stop at line	stop - stop at the line
16	stop - treat as stop sign	stop - stop and look for traffic
17	stop for cross traffic - treat as 4-way stop	stop for emergency vehicles - stop
18	4-way stop - stop and wait for my turn	broken light - unsure
19	flashing red - stop	broken light - stop
20	stop sign - brake and assess	Yield - treat as yield sign
21	signal broken treat as stop sign	Questionnable - stop and survey intersection (possible malfunction)
22	stop - stop at intersection	Broken light - beware of intersection

Appendix C: Driving Study Instructions Sheet

In this driving simulation, you will be driving a vehicle through rural and populated environments. While driving please obey the following guidelines:

Primary Driving Objectives

1) Maintain a speed of 55 mph
2) Obey all posted traffic signs and signals

Other Driving Objectives

3) Stay in the Left Lane
4) Drive in an appropriate manor

In addition to the driving task, you will be asked to perform a secondary task (monitoring traffic) to make the driving experience more realistic.

While driving, you are asked to call out the color of each vehicle you pass. These vehicles will either be driving on the road or stopped at an intersection and will fall into one of three color categories:

Possible Colors
Blue
Red
Yellow

As you see the vehicle, call out (aloud) the color of the vehicle you see.

During the simulation, it is possible you will collide with another car. As a driver, you should try to avoid a collision if at all possible while keeping your and other drivers' safety in mind. If a collision does occur, the simulation will restart in the same location the accident occurred and you will continue on with the simulation.

Remember, at any time if you begin to feel uncomfortable or decide you do not wish to participate any more, you may stop with no questions asked. If you choose to stop participation or decide after completion of the simulation you wish not to be part of the study, your data will be discarded.

This simulation should take you approximately 35 minutes to complete from the beginning of the simulation. If any problems occur during the simulation, either with the simulation program or your driving, you may be asked to restart the simulation.

If you have any questions, please ask the experimenter before the beginning of the simulation. Once you have completed these instructions, tell the experimenter so that he/she may begin the simulation.

Appendix D: Debrief Sheet

Debriefing

Thank you for participating in our study. In this study featuring novel research, it was necessary to conceal our hypotheses because when people know what is being studied they often alter their driving behavior and can be distracted looking for the new signals. However, we do not want you to leave misinformed, so we will now tell you what we were actually studying.

The purpose of this study is to test the feasibility and reaction times associated with novel traffic signals as warnings for impending cross-path collisions.

In order to test these hypotheses, the signals were used in the simulation as warnings at several intersections you encountered. There were two novel signals, one with a growing red light and one that flashed a "do not enter" signal. These signs were placed on traffic lights to simulate a real world warning to you, the driver, that a car was approaching and was going to run their red light. Your reaction time to initiate braking was the key factor we were interested in. This reaction time allows us to determine if these novel signals are more effective at signaling a driver to stop in the impending crash situation than a normal red light.

We apologize that we could not reveal our true hypotheses to you up front, but we hope you can see why it was necessary to keep this information from you. When people know exactly what the researcher is studying, they often change their behavior, thus making their responses unusable for drawing conclusions about human nature and experiences. **For this reason, we ask that you please not discuss this study with other students who might participate anytime in the next year. Thank you for your cooperation.**

If your participation in this study has in any way upset you, please feel free to set up an appointment with one of OU's licensed psychologists or counselors. Counseling and Testing Services is located on the second floor of Goddard Health Center, and they can be reached at (405) 325-2911 or 325-2700.

If you have any questions about this study, feel free to ask the researcher (cell: 918-231-4014, email: rygiel@ou.edu). Thank you for your help today.

Now that you know the true purpose of this study, please check this box if you would like your data to be excluded from our study:

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Signature of Participant or Participant # Date