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Connected and Automated Vehicle Based Intersection Maneuver Assist Systems (CAVIMAS) and Their Impact on Driver Behavior, Acceptance, and Safety

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16. Abstract
Intersection crashes can be potentially mitigated by leveraging deployments of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) safety management solutions. However, it is equally critical that these deployments are undertaken in tandem with interventions based on human factors evidence relating to the content and presentation of such solutions. This driving simulator study designed and evaluated a conceptual system - Connected and Automated Vehicle based Intersection Maneuver Assist Systems (CAVIMAS) - aimed at assisting drivers with intersection maneuvers by leveraging connected infrastructure and providing real-time guidance and warnings and active vehicle controls. Results indicate that human factors considerations for the design and deployment of such systems remain paramount, given the findings related to drivers' trust and acceptance of these systems as measured via surveys and by examining actual driving behaviors.

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1. Abstract

40% of the estimated 5.8 million crashes in the US in 2008 were intersection-related, with most of these having driver-related reasons attributed as the critical reasons for the crashes. A large number of these human-related critical reasons can be potentially mitigated by leveraging thoughtful deployments of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) safety management solutions. However, it is equally critical that these deployments are undertaken in tandem with interventions based on humanfactors evidence relating to the content and presentation of such solutions. To that end, this study designed and subsequently evaluated a conceptual system - Connected and Automated Vehicle based Intersection Maneuver Assist Systems (CAVIMAS) - aimed at assisting drivers with intersection maneuvers by leveraging connected infrastructure and providing real-time guidance and warnings and active vehicle controls. The study was undertaken in an advanced driving simulation environment, and the concept was evaluated via a user study to investigate drivers' interactions with such systems, including their perceptions, acceptance, and trust-related behaviors. Results indicate that human factors considerations for the design and deployment of such systems remain paramount, given the findings related to drivers' trust and acceptance of these systems as measured via surveys and by examining actual driving behaviors.

2. Introduction

Of the estimated 5.8 million crashes in the US in 2008, about 40% were intersection-related (NHTSA, 2009). Intersections are inherently hazardous due to converging travel paths which increase the potential for crashes. A study that examined characteristics of motor-vehicle crashes found that 96% of the intersection crashes studied from the National Motor Vehicle Crash Causation Study (NMVCCS) had driver-related reasons attributed as the critical reasons for the crashes (Choi et al, 2010). This study showed that, of the 756,570 intersection-related crashes with driver-attributed critical reasons, the following were the most frequent critical reasons: "*Inadequate surveillance (44.1%), False assumption of other's action (8.4%), Turned with obstructed view (7.8%), Illegal maneuver (6.8%), Internal distraction (5.7%), and Misjudgment of gap or other's speed (5.5%).*" (Ibid.)

These driver-related critical reasons are of importance and interest given the potential to mitigate them by using in-vehicle collision warning systems (Balk & Yang, 2014), and by leveraging connected and automated technologies (Ibanez-Guzman et al, 2010). In-vehicle collision warnings assist drivers in improving decision making and reaction time in conflict situations, thus helping reduce crashes and injuries. While much of the current in-vehicle warning systems rely on sensors already in the vehicle, there is significant technological scope for leveraging advanced communication technologies to augment the sensing and warning capabilities of vehicles. These technologies, loosely termed as Vehicle-to-vehicle communication (V2V), use dedicated short-range communication (DSRC) to constantly broadcast specific vehicle and traffic related information, including vehicle speeds, position, heading, etc.

Many of the above-mentioned critical reasons for crashes have the potential to be mitigated by leveraging thoughtful deployments of in-vehicle warning systems that leverage vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) safety management solutions, in tandem with human factors-based interventions relating to the content and presentation of such solutions. The latter is an especially critical component given that many of the above reasons are typically related to the visual domain and include a failure to see or recognize relevant traffic control devices (McGwin and Brown, 1999), to perceive cross traffic (Caird et al., 2007), or appropriately judge the distance or speed of oncoming traffic (Guerrier et al.,1999).

Previous laboratory studies have investigated whether advanced in-vehicle warnings could enhance drivers' intersection performances (Balk & Yang, 2014; Caird et al., 2008; Becic et al., 2012), and a test-track study by Nowakowski and colleagues (2008) examined how timeline settings of left turn warnings could impact on drivers' behavior. With the rapid development of connected and automated (CAV) technologies, similar but further work is needed to investigate drivers' interactions with such intelligent intersection assistance systems, including their perceptions, acceptance, and trust-related behaviors. This research study was thus undertaken to design and develop a conceptual system - Connected and Automated Vehicle based Intersection Maneuver Assist Systems (CAVIMAS) - aimed at assisting drivers with different intersection maneuvers by leveraging connected infrastructure and by providing real-time guidance, assistance, and warnings, as well as active vehicle controls.

3. Objectives

The main objective of this study was to conduct a human factors evaluation of drivers' interactions with a conceptual driver assist system (Connected and Automated Vehicle based Intersection Maneuver Assist System - CAVIMAS). The system was designed to mitigate risks at intersections by providing real-time in-vehicle guidance, warnings, and driver assistance by leveraging connected infrastructure and automated control. To achieve the stated objective, the study established the following specific aims: To develop a conceptual intersection maneuver assistance system in a simulated driving environment to empirically examine driver behaviors and mental models; and, to examine driver behaviors related to use of in-vehicle interfaces for the system, including integrated driver display warning and vehicle control systems.

4. Methods

This section of this report will focus on describing the technical aspects of this study, including descriptions and design choices for the components of the conceptual system; descriptions of the testing platform for the concept system, and the experimental platform for the evaluation; and, details about the experimental approach including design, experimental conditions, ethical considerations, data collection, and study measures.

4.1 System Concept

A structured design process was undertaken to help establish the parameters for the intersection management system conceptualization, and to address three main design elements related to the proposed system: target intersection scenarios, system implementation (alerts and control), and system interface. A human-centric design process was undertaken that relied on evidence from the scientific literature as well as via expert brainstorming to identify and select relevant parameters for each of the design elements in an iterative manner.

4.1.1 Intersection Crash types

In terms of the targeted scenarios, i.e., intersection crash types, a selection of common types of intersection crashes from the literature (Ragland & Zabyshny, 2003; Najm et al, 2001) was analyzed through the lens of V2V- or V2I-based interventions, resulting in the identification and selection of three intersection crash types as relevant for the system concept. These are listed below; these crash types and the plan views of the intersections shown in Figure 1 indicate the dynamics and geometry of the crash scenarios.

1. LTAP-OD: Left turn across path - opposite direction
2. LTAP-LD: Left turn across path - lateraldirection
3. SCP: Straight crossing path

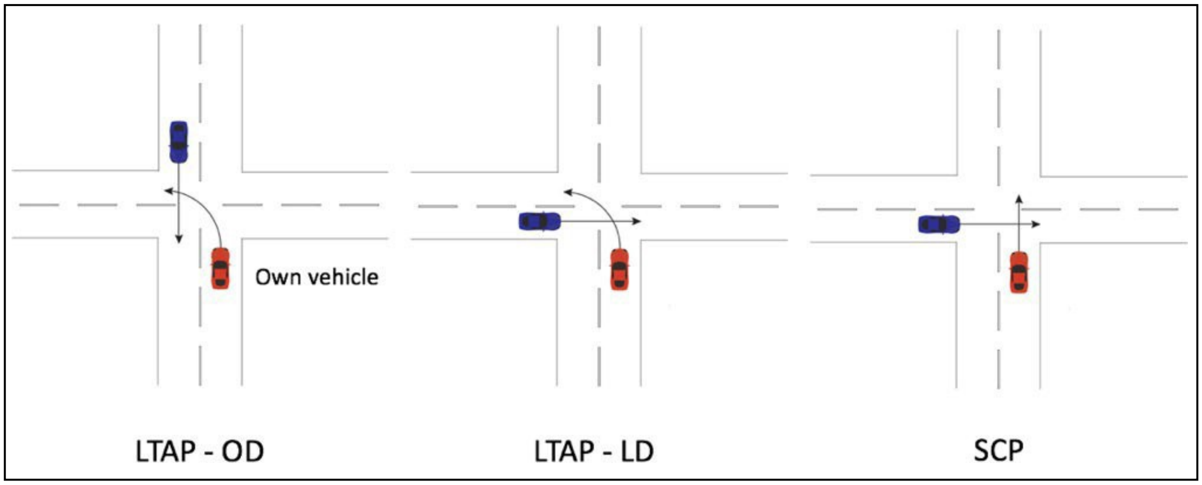


Figure 1 - Crash Types for Intersection Management Assistance System Scenarios

4.1.2 System implementation

For the implementation, the design process culminated in the selection of two concepts that were deemed appropriate as prototypes and for experimental evaluation. An additional baseline concept was also used for experimental purposes. These have been labeled as Systems A, B, and C, and are described in detail below.

System A

System A served as the baseline and was not designed to provide any in-vehicle warnings. The only driver assistance it provided was navigation. Thus, in the driving simulation implementation of this system, the driver received visual and verbal navigational guidance and no other forms of driver assistance.

System B

System B (alert only) was designed to provide information to the drivers about potential conflicts with incoming or cross vehicles at intersections. The concept assumed that the V2V communication between the participant vehicle and the principal other vehicle (POV) would trigger the deployment of information to the driver for appropriate driver actions. Based on the unfolding scenario at an intersection, the driver generally has two options to avoid the three conflicts listed above. This concept was therefore developed so that it could provide two basic driver recommendations, to stop, or to accelerate, to avoid a conflict at an intersection. In its driving simulation implementation, this system calculated the time to collision of the driver's vehicle with that of a principal other vehicle (POV) approaching the intersection and then provided a recommendation to stop or accelerate to the driver via the system HMI.

System C

This concept (alert and automatic control system) was based on the same functionality as System B, but had additional automation capabilities to take over longitudinal controls of the vehicle (braking and acceleration) as needed. In the driving simulation implementation of this concept, as in System B, the system was designed to detect oncoming vehicles and derive the time-to-collision with the driver. However, in System C, instead of simply alerting the driver via the HMI with a recommended action, the system took control of the vehicle's braking or acceleration and invoked automated braking, or automated acceleration, to avoid potential collisions.

4.1.3 User Interface

Along with the system concepts and their implementation, a critical aspect of the design process included the design of the human machine interface (HMI) for the conceptual systems. This design was driven by human factors evidence and best practices for automotive HMI, including guidance on alert modalities and timing. The HMI design for the systems included the alert mode, i.e., visual and auditory, and the alert content, i.e., the specific elements of the visual warnings (and recommendations) including size, position, and color, and the elements of the auditory warning. The following were the HMI implementations for the three systems:

System A

Since this system was used as a baseline concept, the HMI was not designed to provide any alerting information or recommendations to the drivers. The HMI in this case was primarily the visual scenario indicator available on the vehicle instrument cluster.

This scenario indicator (Figure 2) essentially displayed a highly schematic view of the driving scene, as represented by a view of the driver's own vehicle (in blue), the geometry of the roadway (including intersections), and a directional indicator arrow indicating the driver's direction of travel. This schematic view was a static view – there was no real-time "video" of the drive available to the driver on the instrument cluster. This design decision was taken to minimize driver distraction. The static view, however, updated somewhat frequently based on (1) the driver's position from roadway elements, i.e., distance from intersection; and, (2) based on the need to update the navigational aids (arrows). Thus, in System A, the HMI only provided navigational information via the directional arrows and provided no other alerts.

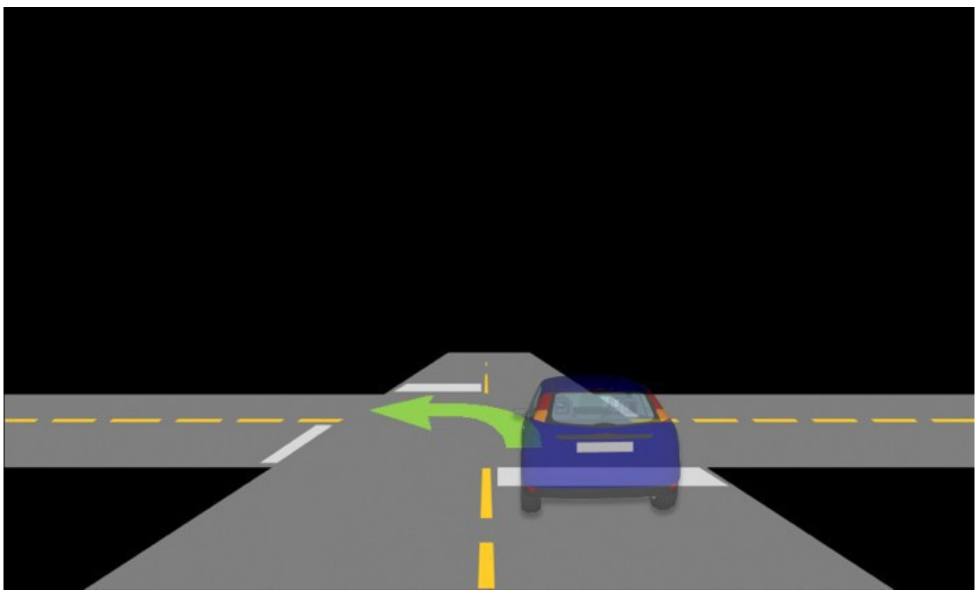


Figure 2 - Example of Scenario Indicator on HMI

System B

The HMI for this system was built on the baseline system. Recall that System B (alert only) was designed to provide information to the drivers about potential conflicts with incoming or cross vehicles at intersections. Therefore, the scenario indicator elements on the instrument cluster included elements in addition to the basic elements in System A (Figure 3). Particularly, the additional elements included (1) a schematic representation of the principal other vehicle (POV) based on the POV's position (red vehicle in Figure 3), updated with distance from vehicle; and, (2) a warning recommendation for driver action (Brake or Speed Up). In addition to these visual elements, the HMI included an auditory alert with 5 short beeps that coincided with each warning visual.

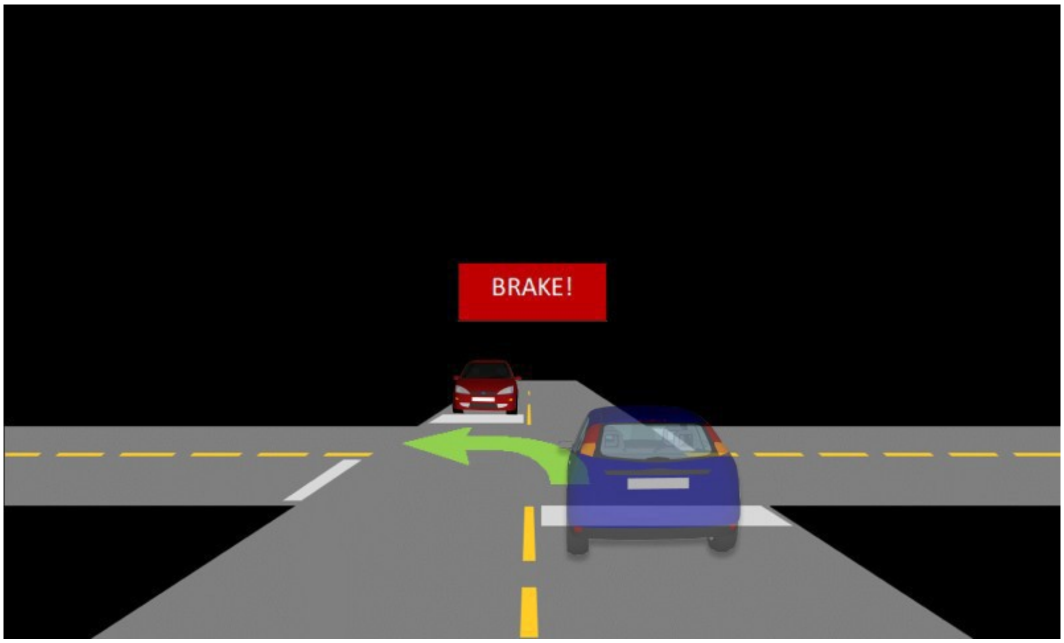


Figure 3 - System B HMI elements, including POV & Warning

System C

This system implementation also included an automated vehicle control system, so the HMI had to be modified from that of System B accordingly. This conceptual system had an HMI implementation very similar to System B, except for the nature of the textual warning provided on the instrument cluster. Whereas the warning on the System B HMI was a recommended action for the driver ("Brake" or "Speed Up"), the System C messages indicated the action that the automation was undertaking, i.e., "Braking" or "Speeding Up" (Figure 4). Other visual and auditory elements of the HMI remained the same as system B.

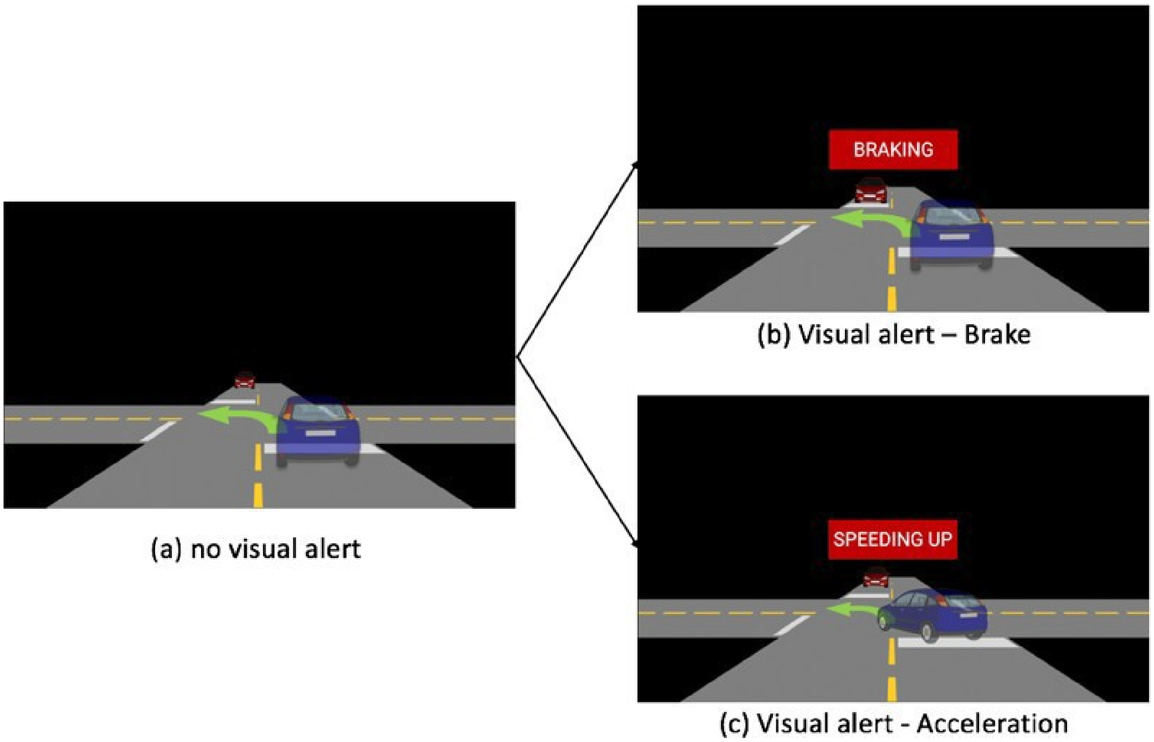


Figure 4 - HMI for System C

4.2 Experimental Platform/Apparatus

The conceptual systems were designed to be implemented and evaluated in a high-fidelity driving simulation environment. The characteristics and capabilities of the driving simulator platform made it possible to rapidly prototype the system concepts and test various versions iteratively until a usable system concept could be simulated for a user study. The driving simulator platform conferred distinctive advantages to the approach, making it possible to quickly customize the HMI and the alerts, to script the conflict scenarios closely so as to induce realistic warnings or automated actions, and most importantly to take over automated control of the vehicle and away from the driver's control. The driving simulation environment also provided an experimental platform to conduct the user evaluation with high degrees of repeatability and control.

The rest of this section will describe in some detail the apparatus used in this study – namely the driving simulator and the integrated eye tracking system.

4.2.1 Driving Simulator

A high-fidelity advanced driving simulator located at the University of Michigan Transportation Research Institute (UMTRI) was used for this study (Figure 5). The fixed-base simulator was located in a dedicated lab space and comprised of a Nissan Versa sedan, a simulation system running version 2.63 of Realtime Technology's (RTI) simulation engine, SimCreator, and custom code for automated features in the vehicle. The simulator contained 10 central processing units, including a host acting as the operator interface, six Image Generators to render projections, one unit to render the virtual instrument cluster, one unit to log data, and one unit to run an eye-tracking system (See section 4.2.2). Three screens displayed road scenes in front of the vehicle. The screens were 16 feet in front of the car and spanned a 120-degree forward field of view. There was one rear screen about 12 feet away from the driver that spanned a 40-degree field of view. The forward channels were projected at 1400×1050 resolutions and updated at 60Hz.

Figure 5 - High Fidelity Advanced Driving Simulator

The simulator provided the flexibility to create different types of virtual driving worlds and scenarios via a highly programmable system. The virtual worlds could be designed in-house, allowing the creation of a specific driving world for this particular study comprising of a series of intersections to increase the exposure of participants to the evaluated systems. The programming also allowed the scripted manipulation of other roadway and infrastructure elements, including other vehicles and traffic lights, so that the specific scenarios for testing and evaluating these conceptual systems could be programmed in-house as well. Finally, the simulator was capable of recorded multiple categories of driving data including velocity, acceleration, lane position, and video and audio inside the car at 60Hz.

4.2.2 Eye Tracker

The driving simulator had a four-camera remote eye tracker installed in the cab of the vehicle. The eye-tracker, built by Smart Eye AB of Sweden, was closely integrated into the driving simulator environment, both physically, and within the software system (Figure 6). The system provided measurements of eye movement parameters and pupillometry at 60 Hz. These included head-pose, eye-blink, fixation locations, fixation duration, and pupil diameter among others. The eye-movement data were integrated with the driving simulator software that permitted recognition of point of gaze on objects situated in the physical and virtual space.

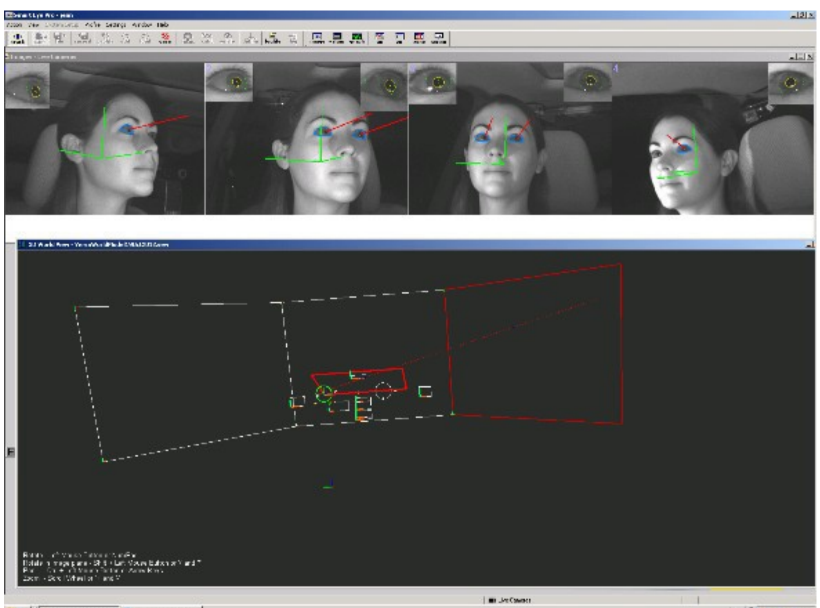


Figure 6 - Integrated Eye Tracking System

4.3 Experimental Design

For the evaluation aspect of this study, an experiment was conducted with human participants to examine the conceptual systems from a human factors perspective. In brief, an experiment was designed to measure driver reactions and performance to the intersection maneuver assistance systems. An experimental approach was taken wherein naïve drivers were recruited to participate in a driving simulator study where they experienced and interacted with the conceptual systems as well as a series of baseline scenarios in simulated drives. Objective driver behavior measures were recorded from the simulator and the eye tracker. The participants also responded to survey measures designed to collect information about use preference, perceptions, and acceptance.

The study employed a within-subject experimental design, with each subject being exposed to baseline (no assistance) and experimental (with assistance) scenarios. Objective simulator and eye tracker measures were compared within subjects, evaluating performance at both conditions. This section details all elements of the experimental study, including the design of said experiment, the experimental scenarios, human participant details, data collection and dependent variables, and the experimental procedures.

4.3.1 IRB

Given that the study had a human participant component to it with the evaluation user-study, appropriate approvals had to be received from the Institutional Review Board (IRB) to ensure protection of human participants' rights, safety, privacy, and for data security. IRB approval was thus applied for and permission was granted to conduct the human subject study. All recruitment and screening material (flyers, emails, screening questions), informed consent language, study protocol, data security protocols, and study surveys were approved for use in the study by the IRB. Appendix A contains the Informed Consent Form and the screening questions used for the study.

4.3.2 Participants

A total of 24 licensed drivers (15 males and 9 females; age mean = 23.9, SD = 6.2) were successfully recruited and scheduled for the study. Participants were recruited using various techniques, including flyers, postings on social media, and through existing participant lists. Drivers were screened, either by phone or email, for various inclusion criteria prior to being scheduled to participate in the study, including criteria such as age, sufficient vision, frequency of driving, etc. Inclusion criteria included having normal or corrected-to-normal vision, holding a valid US driver's license, driving at least twice a week, and an age between 20-55. (Appendix A). Participants who wore glasses were excluded, but contact lenses were allowable. Participants were also screened for susceptibility to simulator sickness. Participants were compensated $40 for the study, which lasted approximately 90 minutes, with the simulation drives not exceeding 20-40 minutes cumulatively.

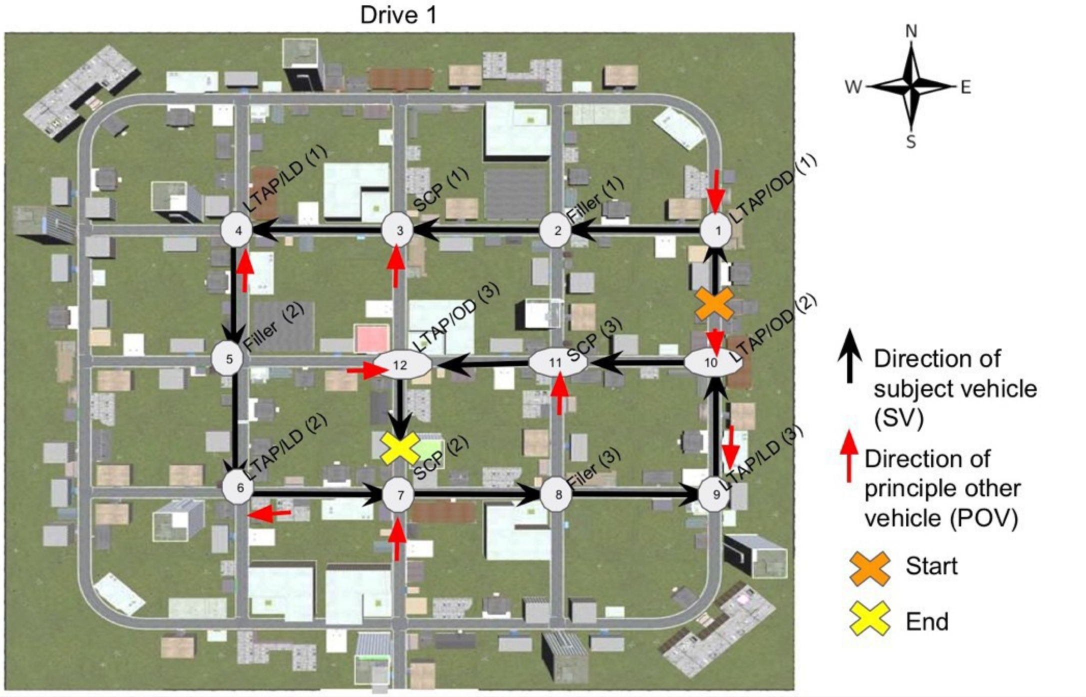
4.3.3 Driving Simulation Drives & Scenarios

For the experimental evaluation of driver behavior and perceptions of the conceptual systems, the driving simulation platform had to be programmed to present a virtual driving environment to the human participants to elicit said behaviors. To that end, four virtual drives were designed and developed. All virtual drives were programmed to represent a drive in a city environment with multiple controlled intersections, other traffic elements, and the roadway laid out in a grid formation. One of the drives served as a 'practice drive', which was designed to familiarize the participant with the driving simulator and its controls and visuals, to familiarize the driver with the conceptual systems and associated HMI, and to provide enough practice driving the simulator. The other three drives were the experimental drives, each of which were associated with System A (Drive 1), B (Drive 2a), or C (Drive 2b). Each of the drives took about 5-8 minutes to complete.

All three drives presented the participant with multiple intersections as he/she navigated the virtual world. Navigation information was provided by a virtual navigation system that included spoken instructions e.g., “turn left at the next intersection”, and the navigational arrows in the HMI. Since the drives were designed for presenting each of the three systems, the scenarios (or events) that were designed for the intersections were programmed accordingly.

For each drive, the participant was exposed to a dozen intersections. Of these, four were what were termed as ‘filler’ intersections, wherein there were no actual or perceived conflicts with other vehicles. The remainder were the actual experimental scenarios developed to simulate one of the three high-risk intersection crash scenario types: LTAP/OD, LTAP/LD, and SCP. Figure 7 illustrates a single experimental drive with the scripted driver route, the filler intersections, and the experimental intersections.

Three instances of each of these scenario types were developed, to represent situations where the participant either had to brake, to accelerate, or did not have to react (no-conflict). The drives, and the scenarios in particular, were programmed so that the intersection scenarios as well as the non-intersection drives would feel and look like natural driving. During the non-intersection drives, the participant passed or encountered other traffic in opposite lanes with no conflicts. In the experimental intersection scenarios, the participants encountered near-critical events with vehicles approaching the intersections from ahead (LTAP/OD) (Figure 8), or as cross traffic (LTAP/LD, SCP) (Figure 9, Figure 10).



1	LTAP/OD (1)	SV starting and going to North and turning left to West. POV approaching from North to South.	POV 300 ft away with speed of 20 mph, No response required from SV
2	Filler (1)	SV going to West.	
3	SCP (1)	SV going to West. POV approaching from South	POV 300 ft away with speed of 20 mph, No response required from SV
4	LTAP/LD (1)	SV going to West and turning left to South. POV approaching from South to North.	POV 300 ft away with speed of 20 mph, No response required from SV
5	Filler (2)	SV going to South.	
6	LTAP/LD (2)	SV going to South and turning left to East. POV approaching from East to West.	POV 200 ft away with speed of 40 mph, SV is required to Brake.
7	SCP (2)	SV going to East. POV approaching from South to North.	POV 200 ft away with speed of 40 mph, SV is required to Brake.
8	Filler (3)	SV going to East.	
9	LTAP/LD (3)	SV going to East and turning left to North. POV approaching from North to South.	POV 200 ft away with speed of 20 mph, SV is required to Accelerate.
10	LTAP/OD (2)	SV going to North and turning left to West. POV approaching from North to South.	POV 200 ft away with speed of 40 mph, SV is required to Brake.
11	SCP (3)	SV going to West. POV approaching from South to North.	POV 200 ft away with speed of 20 mph, SV is required to Accelerate.
12	LTAP/OD (3)	SV going to West and turning left to South, and stopping. POV approaching from West to East.	POV 200 ft away with speed of 20 mph, SV is required to Accelerate.

Figure 7 - Plan view of an experimental drive with scenario & filler descriptions

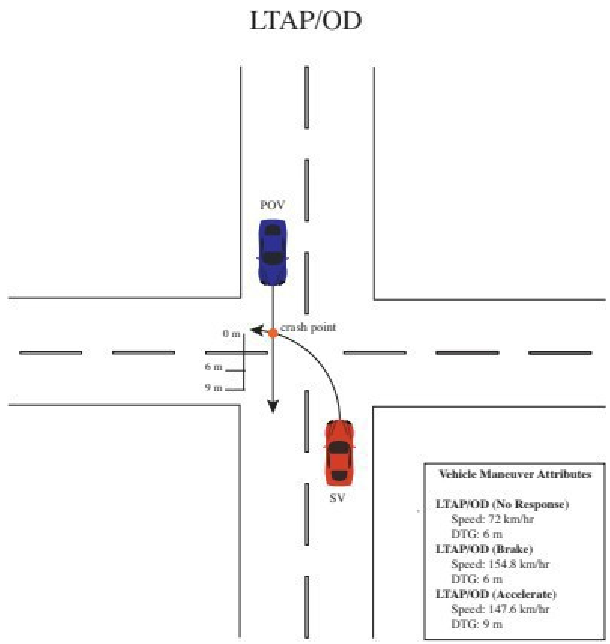


Figure 8 - Schematic of an LTAP/OD simulated scenario

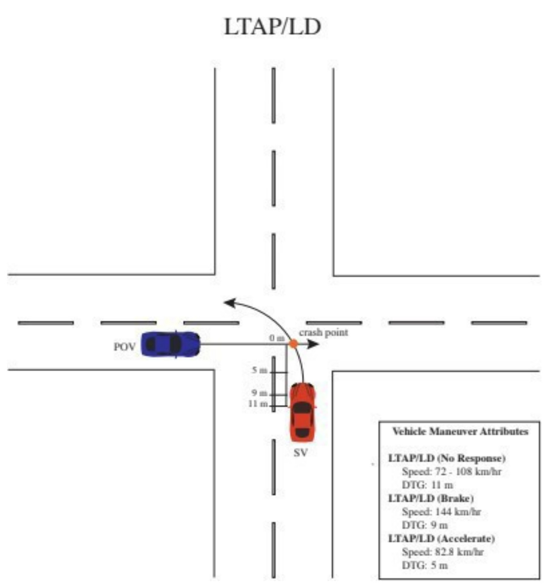


Figure 9 - Schematic of an LTAP/LD simulated scenario

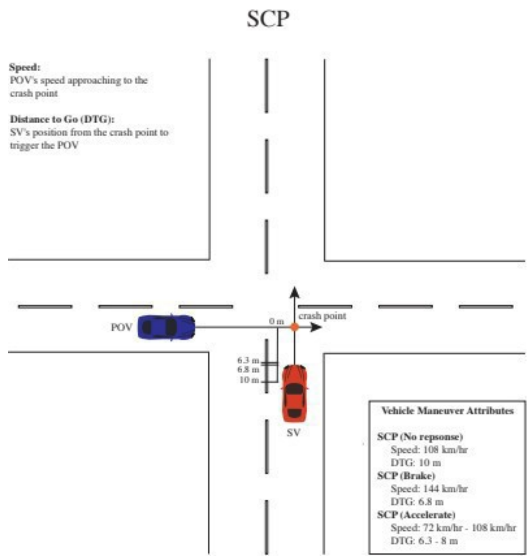


Figure 10 - Schematic of an SCP simulated scenario

4.3.4 Procedure

Each participant, after successful screening and recruitment, was scheduled to appear at the driving simulation laboratory for the actual data collection. As mentioned previously, each participant spent about an hour for the experiment, with about half of that time actually spent in driving the simulator. The following sections describe the protocol and procedure for data collection for each participant.

Upon arrival at the laboratory, each participant was greeted by the researcher and was first provided with an informed consent form to read and complete. The researcher conducting the study was available to answer any questions about the informed consent. Upon completing the informed consent form, participants were given a pre-survey on a tablet to gather demographic information and record self-reported driving habits. They were then instructed to sit in the driving simulation cab and adjust the seat as if they were driving in the real world. The participants then underwent a calibration process for the eye tracking system. As part of this procedure the researcher instructed the participant to look at certain images on the center screen while the system was calibrated for each participant's particular seating configurations. The eye-tracking calibration generally took less than 2-3 minutes.

The participants were then familiarized with the driving simulator. This was first done as a verbal overview by the researcher who spoke about the simulator, about safety, and about driving in the simulator as 'one would in the real world'. The participants were then presented with the practice drive that allowed them to actually drive the vehicle for acclimatization purposes. The practice drive was about 5 seconds long and was representative of the experimental drives, in the sense similar types of road way geometries and intersections were encountered by the participant. Participants were then asked if they felt comfortable to proceed with the experimental drives. Participants had the option to redo the practice drive if they so wished, but no participants undertook the practice drive more than once.

The participants were then presented with the experimental drives. Participants were randomly assigned to one of two groups. In both groups, participants first drove a baseline (Drive 1), then one of two experimental drives (Drive 2a or Drive 2b) according to group allocation. Drive 1 presented intersection scenarios with no assistance systems (i.e., System A). Drive 2a presented visual and auditory warnings about intersection conflicts and recommended response options (brake or accelerate) if necessary (i.e., System B). Participants were asked to respond to the warnings by braking or accelerating, but were free to ignore the recommendations. Drive 2b presented visual and auditory warnings, with the vehicle automatically responding to the conflicts by accelerating or braking (i.e., System C). All drives took place in a city-like environment with a grid layout and multiple intersections (Figure 7). In all of the drives, participants were tasked with following audio navigation instructions from the driving simulator: Drivers were instructed to either turn left or to continue straight at the intersections. The drives contained filler intersections, where the participants were not expected to brake or accelerate, and common crash scenarios LTAP-OD, LTAP-LD, and SCP - where an action was required to avoid an accident. Each drive lasted approximately 5-8 minutes. After each drive, participants took two surveys - one regarding decisions made during the preceding simulation and one to measure driver workload. Figure 11 shows the driving simulation environment in the top three panels, and a view of the driver, the vehicle HMI, and the vehicle foot well in the lower panels.

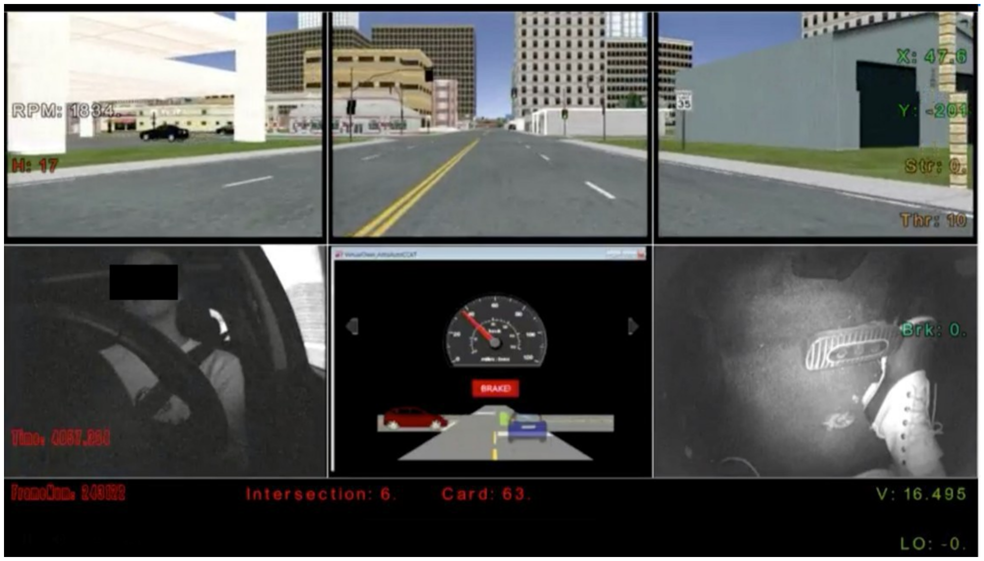


Figure 11 - Illustration of driving simulation environment, system HMI images, and view of driver

4.3.5 Dependent Measures and Data Collection

For measurement and evaluation of driver behaviors, various categories of outcome measures were collected from the participants during the driving simulation experiment. The main variables of interest were recorded during the intersection scenarios and during the baseline scenarios. These categories of outcome measures included driving simulator measures, where the outcome measures of interest included: reaction time, vehicle kinematics and position, driver behaviors (e.g., hand position, affect, posture), and driver maneuver choices. These outcome measures were selected to allow an examination of participants' overt intentions, acceptance, and reactions to the messaging system.

Another category comprised physiological measures (eye movement). The outcome measures of interest included: overall visual glance patterns; in-vehicle glances/time eyes-off-road; and, glances at the warning interfaces. These variables offered insight into elements of attention and situational awareness during the messaging tasks. One important measure derived from this category of data is for hazard perception. This measures whether or not a participant was aware of potential risks and hazards on the roadway. This was operationalized by measuring lookout behaviors at intersections as well as visual gaze behavior at the HMI elements, such as the instrument panel. Another outcome measures category was subjective post-drive surveys. Participants were asked to complete two surveys after each of their drives. The first survey presented participants with animations of scenarios they experienced in the preceding drive along with questions aimed to determine the helpfulness of the visualizations, accuracy of the warnings, and driver confidence in turning at intersections, amongst other measures. The second survey participants received after completion of a drive was a Task Load Index (TLX) survey. This type of survey is a modified and simplified version of the NASA-TLX. The NASA-TLX survey is a multidimensional scale designed to measure workload associated with completing a specific task. Subscales used in this study were mental, physical, temporal demands, frustration, effort and performance (NASA, 1986). The participants also completed survey measures designed to collect information about demographics, user preference, perceptions, and acceptance.

5. Analyses

Analyses were conducted to examine driver response and behaviors for the outcome measures listed above for various scenarios. Within-subject comparisons were conducted to examine differences in driver behaviors between baseline and experimental conditions. Analyses of the subjective measures focused on identifying key themes, with particular emphasis on driver acceptance. For trust and confidence scores, a two-sample t-test was used to examine difference between drives. The normality assumption of the t-test was verified, using the criteria of skewness (<2) and kurtosis (<7) (Curran, West, and Finch 1996). The task load index measures were analyzed with the Mann-Whitney U test to compare the difference between each of systems and baseline. Analyses were also conducted to understand visual behaviors while engaged in the concept systems. For monitoring time on IP, analysis of variance (ANOVA) was used to examine the difference among the intersection types and systems after it was cube-transformed to achieve normality. Additionally, Tukey's honest significant difference (HSD) was used as a post hoc test. Differences between the systems in drivers' hazard perception were explored with Pearson's chi-square test. In addition, logistic regression was used to analyze the differences in the systems regarding the likelihood of hazard perception. All statistical analyses were performed with RStudio Version 1.1.463.

6. Results

6.1 Surveys

A baseline questionnaire asked participants about their perceptions of their own driving abilities and on their attitudes towards intersection related warning systems. As seen from Table 1, drivers had high confidence in their own driving abilities and skills at intersections, but at the same time, a large majority of these drivers agreed that it would be helpful if their own vehicle had warning systems that helped them at intersections.

	"I trust my driving abilities and skills at intersections." n (%)	"It would be helpful if my vehicle had warning systems that helped me at intersections." n (%)
1 – Strongly disagree	0 (0.0)	0 (0.0)
2	1 (4.2)	2 (8.3)
3	0 (0.0)	4 (16.7)
4	12 (50.0)	10 (41.7)
5 – Strongly agree	11 (45.8)	8 (33.0)

Table 1 - Drivers' Evaluation of Driving Skills and Helpfulness of Warning System

Participants expressed more confidence in being able to manage all three intersection scenarios (i.e., turn left in front of an incoming vehicle for LTAP-OD and LTAP-LD and proceed through for SCP) in Drive 2a as compared to Drive 2b (Figure12). Participants also reported being able to better judge the speed of the incoming vehicles in Drive 2a as compared to Drive 2b (Figure 13). A t-test reveals that the confidence score (that combined the responses to two confidence questions) is significantly higher for

Drive 2a (M = 4.78, SE = 0.17) than Drive 2b (M = 3.82, SE =0.22); t(132.56) = 3.50, p < .001 (Figure 14).

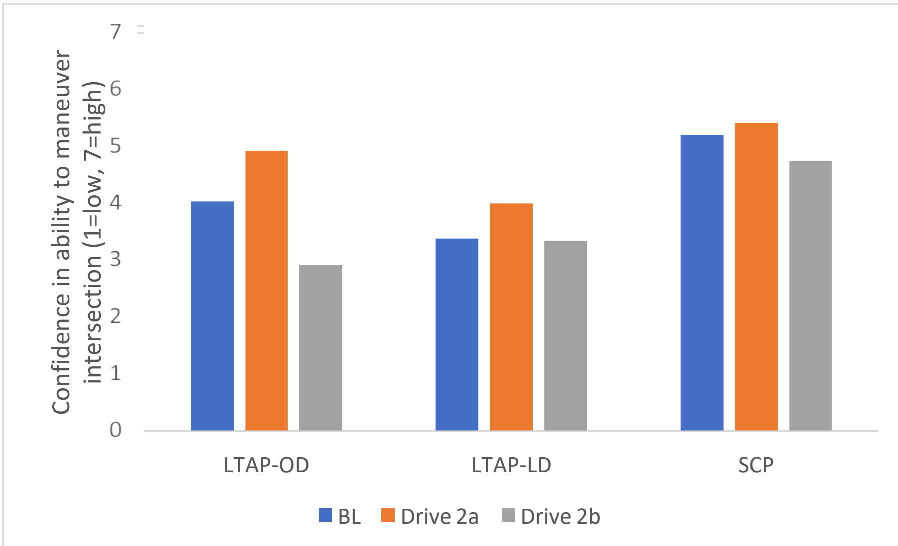


Figure 12 - Confidence in maneuvering intersection

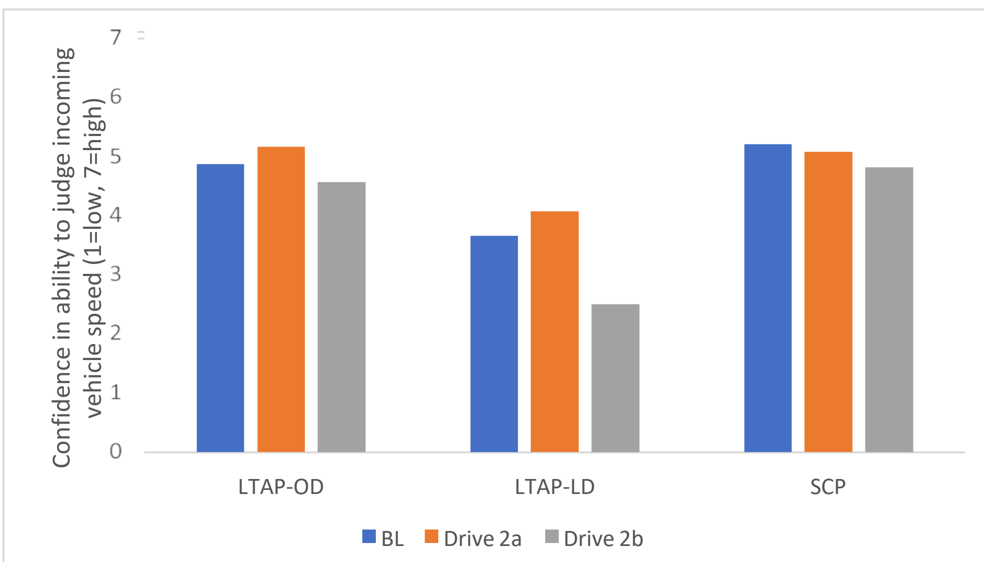


Figure 13 - Confidence in ability to judge speed

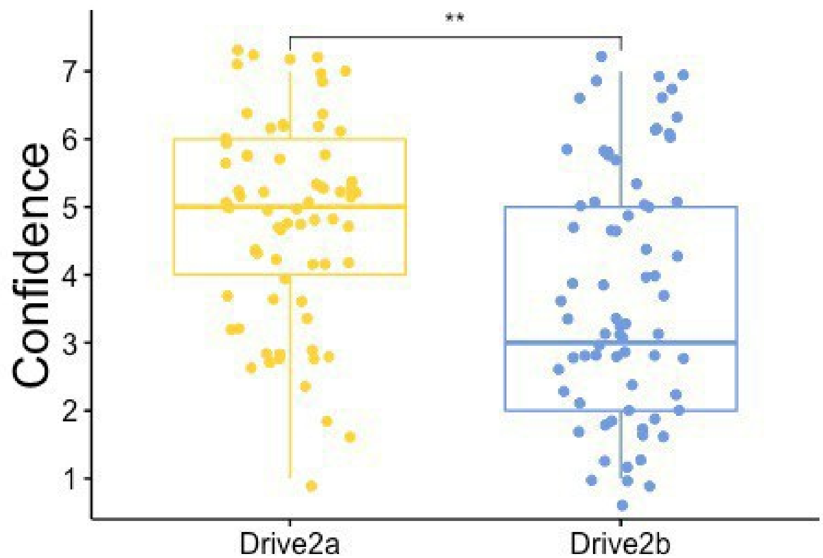


Figure 14 - Driver Confidence in Drives 2a and 2b

Participants also generally had a positive perception of the technologies of the conceptual systems, as illustrated by the survey responses in Figure 15. Drivers found the intent of the system clear and system recommendations and alerts generally timely. They found audio alerts easier to understand than visual alerts.

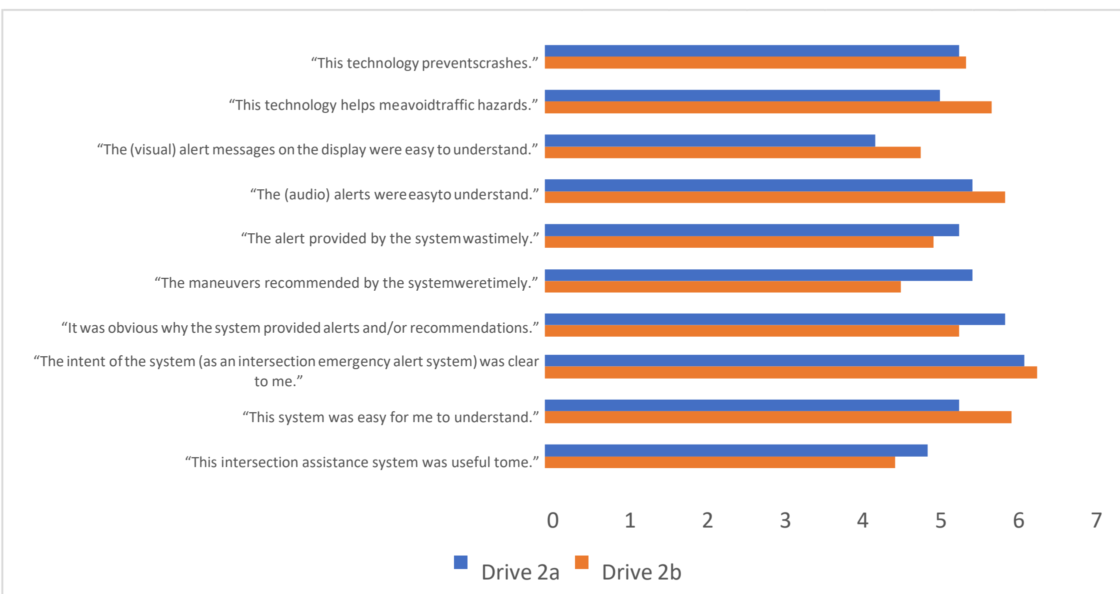


Figure 15 - Drivers' Assessment of the Intersection Assistance System in Experimental Drives

To examine participants' attitudes towards the specific elements of the assistance system for System B, they were asked about their perceptions about the recommendations for braking and acceleration separately. The results show a clear bifurcation of the responses for Braking versus Acceleration (Figure 16), with all drivers at least somewhat agreeing that they felt comfortable with the braking recommendation, and all drivers at least somewhat disagreeing that they were comfortable with the acceleration recommendation.

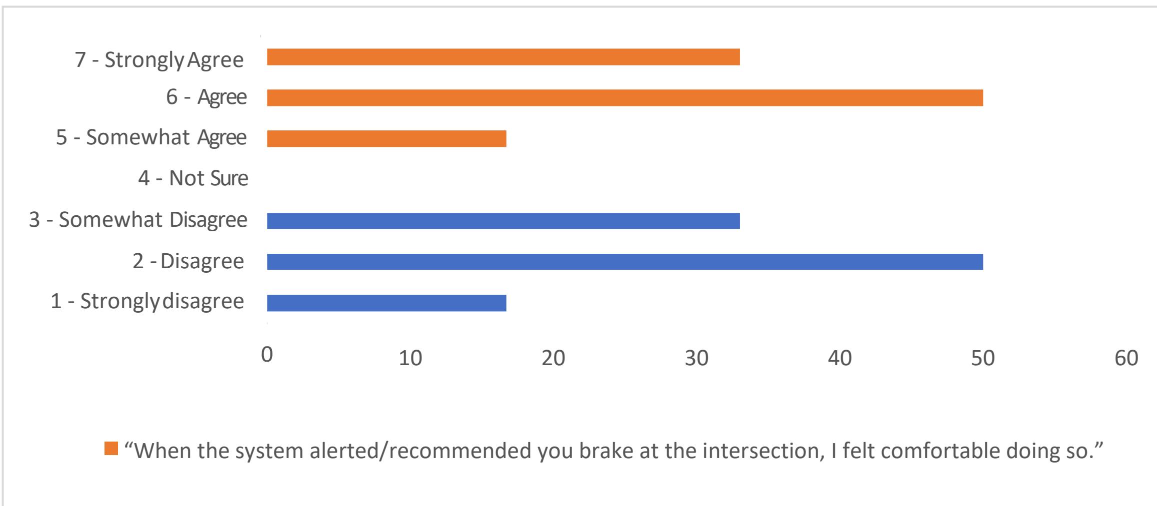


Figure 16 - Assessing Recommendations of the Intersection Assistance System

Driver assessments of System C, i.e., the system with the automatic braking or automatic acceleration features, were specifically conducted through survey items to examine driver's acceptance and trust of this concept, given its novelty as compared to System B. When asked if the systems provided appropriate and timely alerts for the automatic braking and acceleration, a majority of users expressed satisfaction with the alerting for the braking, but that result was reversed for the acceleration feature (Figure 17).

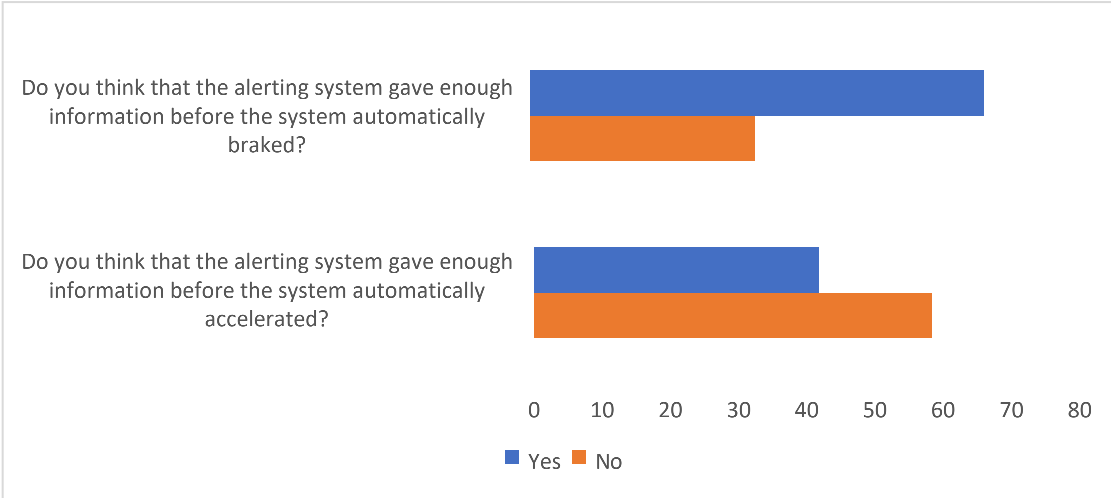


Figure 17 - Drivers' Assessment of Alerts for Auto-Accelerate/Brake

A related question about the level of customization participants would like over the vehicle automation indicated that the vast majority of the respondents preferred that users have the option to turn the system on or off (Figure 18).

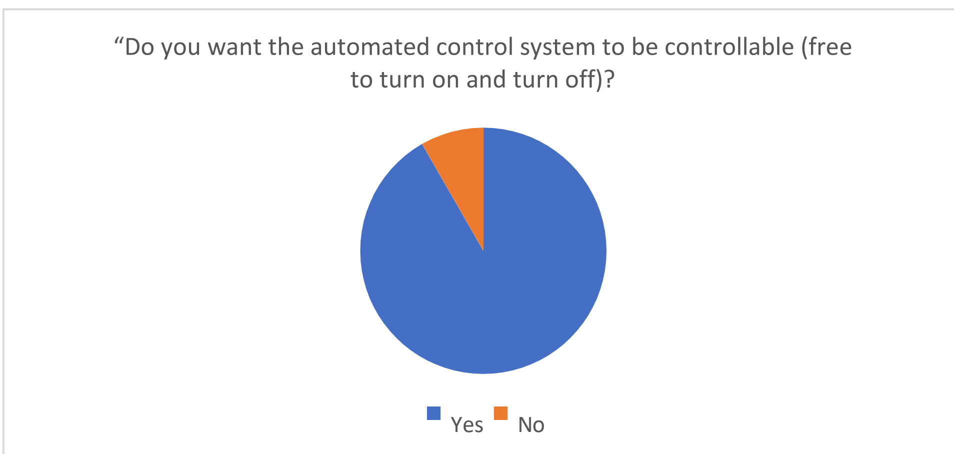


Figure 18 - User control of automation features

A critical aspect of the driver perception surveys was related to driver trust and acceptance of the conceptual systems. For that an analysis was conducted to compare attitudes towards System B and System C, effectively comparing a warning only system with a system that had automated vehicle controls. Results indicate that a slightly higher percentage of drivers (58% vs 50%) indicated that they trusted Drive2a (system with no automation) than Drive 2b (with automated control).

Drivers were more confident in the auto-braking system than the auto-acceleration system and tend to trust the braking was timelier and more accurate. There was a significant difference in the trust scores for Auto-acceleration (M = 4.29, SE = 0.25) and Auto-braking (M = 5.15, SE = 0.19) conditions; t(86.9) = -2,71, p < .01 (Figure 19). Some drivers mentioned that they felt dangerous when auto-acceleration was activated, although drivers were satisfied with automatic braking features that can help them avoid crashes.

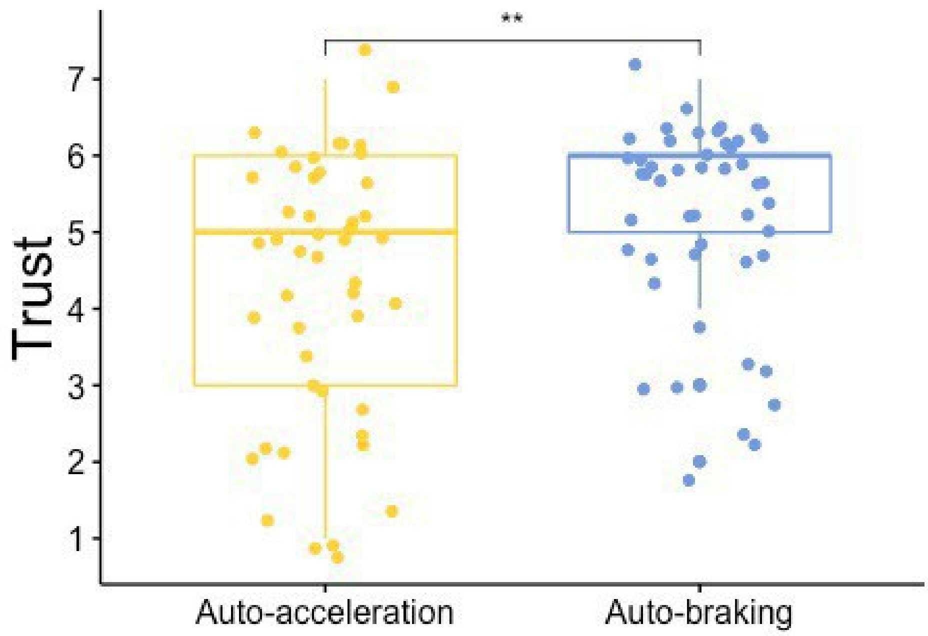


Figure 19 - Driver Trust in Automatic Control

Results also indicated that, for Drive 2a, although the systems provided maneuver response recommendations based on the contextual dynamics of an intersection, the participants' responses were not necessarily in line with the recommendations. This was especially the case for scenarios where the system recommended acceleration, but the overwhelmingly preferred response was to brake. This reversed behavior was not observed for the braking recommendation scenarios (most participants braked when asked to brake). Similar behavior was observed for Drive 2b, where, despite the automatic control accelerating the vehicle, the participant either overrode by braking, or hovered their foot over the brake pedal while automatic acceleration was being undertaken.

6.2 Driver Workload

To measure driver workload caused by the various conceptual systems, each participant completed the NASA-TLX (Hart, 2006). The shortened version of the test was used (without the pairwise comparison) given the evidence of increased experimental validity with the short version (Bustamante, 2008).

Figure 20 shows the rating scores on each NASA-TLX subscale for the comparison between Baseline and Drive 2a. Figure 21 shows the comparison between Baseline and Drive 2b. None of Mann-Whitney U tests showed significant effects of System on any of subscale of NASA-TLX.

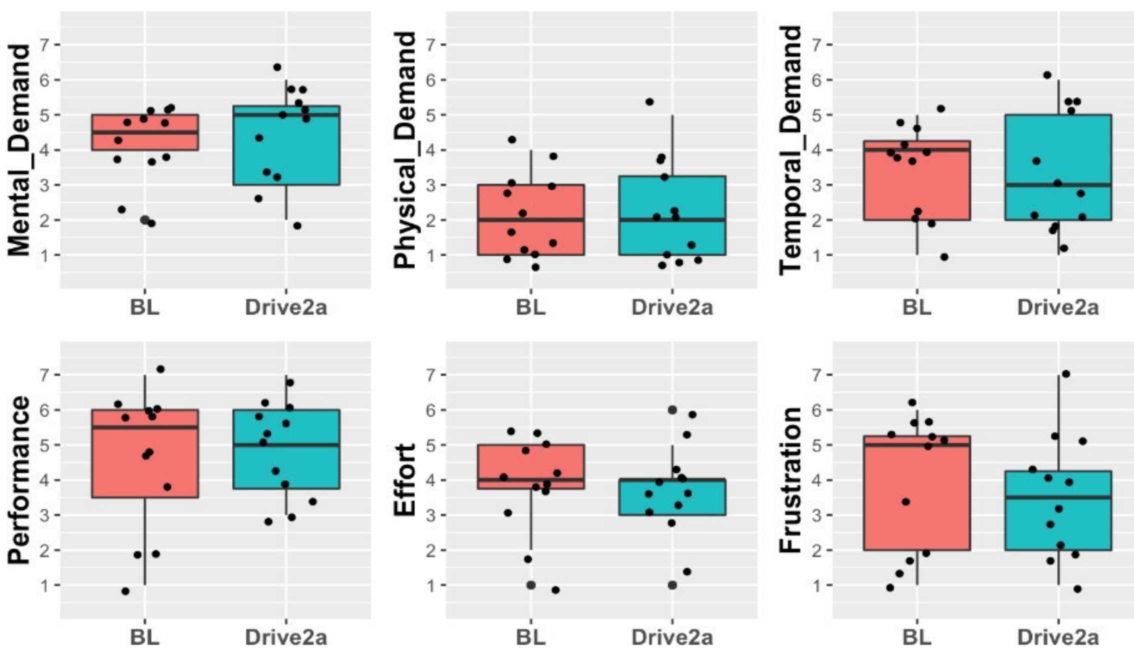


Figure 20 - NASA-TLX comparison between Baseline and Drive 2a

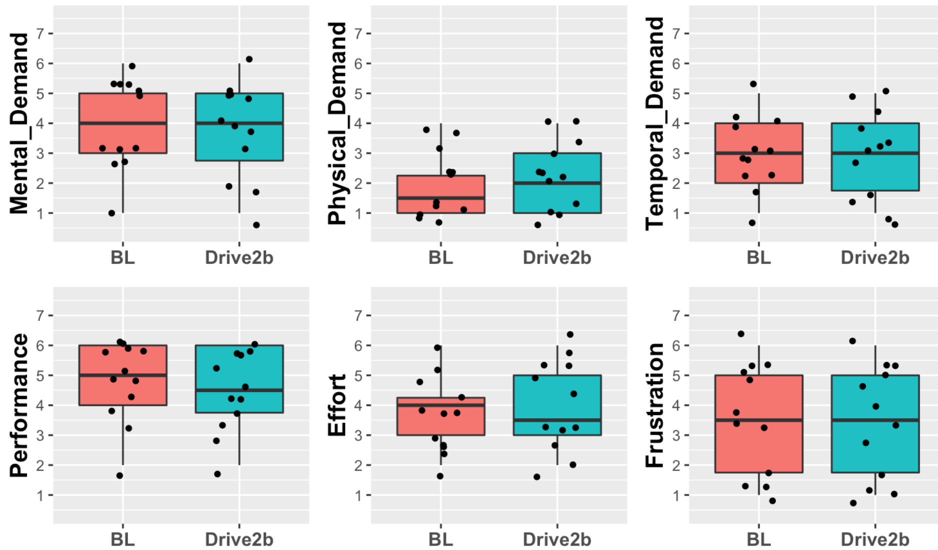


Figure 21 - NASA-TLX comparison between Baseline and Drive 2b

6.3 Hazard Anticipation

Hazard anticipation errors are a common cause of crashes among adolescent drivers (e.g., McDonald et. al., 2014). Hazard anticipation has been defined as a set of driver behaviors that include, awareness and knowledge of risks and threats to safety, visual search to detect and recognize elements contributing to these threats, prediction of hazards based on current visual information, and the driving responses to minimize conflicts due to recognized hazards (Pradhan & Crundall, 2016; McDonald et al, 2015). Driving-safety-related hazard anticipation behaviors may also be a skill that can inadvertently be affected by the introduction of driver assistance technologies, i.e., negative behavioral adaptation (Sullivan et al, 2016). To examine this issue, analyses were undertaken of the driver visual gaze behavior to study effects of the introduction of these systems on hazard anticipation behaviors. This was done for driver 'lookout' behaviors when maneuvering high risk intersections and for gaze behaviors towards the instrument panel (IP).

Hazard anticipation ability was analyzed separately for intersections depending on the drivers' path of travel, i.e., if they were turning left at an intersection versus if they were going straight through, given the inherent differences in visual search behaviors because of the dynamics and associated risk elements of these intersections and maneuvers. A chi-square test indicated a significant relationship between System and whether or not a driver searched to the right when turning left (Table 2). Drivers in Drive 2a (13.9%) and 2b (6.9%) were less likely to look right compared to those who in the baseline drive (Drive 1) (23.9%). A logistic regression was performed to ascertain the likelihood that participants looked right. The odds of looking right when turning left for someone assisted by System 2b was 0.2 times as low as someone in baseline system (p=0.003). There was no significant difference on the odds ratio between Drives 2a and 2b. Additionally, there was also a significant relationship between System and whether or not a driver scanned to the right and left when proceeding straight through an intersection. Drivers in Drive 2a (11.1%) and 2b (16.7%) were less likely to scan both sides compared to those in Drive 1 (29.0%). A logistic regression analysis was conducted to examine the likelihood that participants scanned both sides when driving straight and found that the odds of scanning for someone assisted by System 2a was 0.31 times as low as someone with baseline system (p<0.046). There was no significant difference on the odds ratio between Drives 2a and 2b.

System	Scanned Right while turning left, n (%)		X-squared	df	p
	Yes	No	1026.2	6	< .0001
BL	33 (23.9)	105 (76.1)			
Drive 2a	10 (13.9)	62 (86.1)			
Drive 2b	5 (6.9)	67 (93.1)			
System	Scanned both sides when driving straight, n (%)		X-squared	df	p
	Yes	No	1032.2	6	< .0001
BL	20 (29.0)	49 (71.0)			
Drive 2a	4 (11.1)	32 (88.9)			
Drive 2b	6 (16.7)	30 (83.3)			

Table 2 - Hazard Anticipation Visual Gaze Behaviors

In terms of the visual gaze behaviors related to monitoring the instrument panel (IP), a chi-square test indicates a significant relationship between Intersection type and IPrelevant visual gaze (Table 3). The SCP type intersection conflicts were associated with more frequent IP checks (97.1%) compared to LTAP-OD (88.6%) or LTAP-LD (85.3%) type scenarios. A logistic regression was performed to ascertain the likelihood that drivers looked at the IP and found that the odds of looking at the IP for someone who drove SCP scenario was 5.8 times as high as someone drove LTAP-LD scenario (p = 0.002) and 4.4 times as high as someone who drove LTAP-OD scenario (p = 0.01). There was no significant difference on the odds ratio between LTAP-OD and LTAP-LD. No significant relationship between System and visual gaze at the IP. For individual systems though, the duration of glances towards the IP were significantly higher for SCP type scenarios for the System A (baseline) and System B (alert only), whereas for System C (with automation) there were significant differences between System A & B, and System B & C (Figure 22)

Intersection Type	Glance at IP n (%)		X-squared	df	P
	Yes	No	11.82	2	.002713
LTAP-LD	116 (85.3)	20 (14.7)			
LTAP-OD	124 (88.6)	16 (11.4)			
SCP	135 (97.1)	4 (2.9)			

Table 3 - Visual gaze on instrument panel (IP)

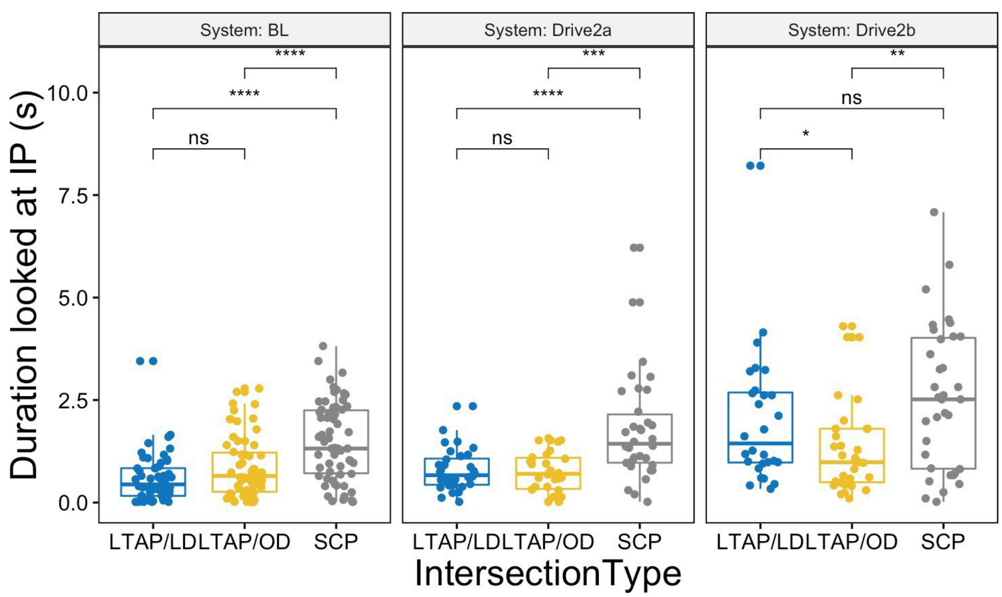


Figure 22 - Gaze duration towards instrument panel (IP)

7. Findings and Recommendations

This study was designed to conceptualize and then evaluate an intelligent Connected and Automated Vehicle Intersection Management Assistance System using driving simulation as the design and experimental platform. The decision to leverage a driving simulation platform for the conceptualization and implementation of the proposed assistance systems, as carried out using a human centric iterative design process, proved to be a sound one. The simulation platform not only allowed for the rapid prototyping of various conceptual systems, and their interfaces, but also provided a realistic and viable platform for actually conducting the user study for the evaluation of the systems.

The results of the evaluation of the systems offer significant insights into both driver attitudes towards intersections and towards warning systems, as well as perceptions and behaviors when using such systems in an experimental context. A telling early finding was that although most of participants (98.8%) responded that they were very confident in their driving abilities and skills at intersections without any assist systems, they paradoxically also stated a preference for intersection maneuver assist systems with more than 70 % of them agreeing that "it would be helpful if my vehicle had warning systems that helped me at intersections". Along that vein, it was also seen that participants had predominantly positive perceptions of aspects of the conceptual systems, especially in terms of constructs such as ease of use or timeliness. The participants indicated that the conceptual systems were easy to use, the messages and alerts were easy to understand as well as timely, the recommendations for action were pertinent, and that there was a general utility to thesystems.

However, the data further did show that in terms of confidence in the systems (especially System B vs System C), there was a significant difference between systems, with participants indicated higher confidence in being able to manage the crash relevant intersection scenarios, and in being able to accurately gauge speeds of the principle other vehicle, for System B (Drive 2a) compared to System C (Drive 2b). In other words, elements of System B, either in terms of the concept, design, or implementation, resulted in a system that was preferred by users. One interpretation of this finding, seen through the lens of locus of control, could be that drivers were generally more confident of their own ability to manage these intersections even if augmented by recommendations. However, when the control was taken away from them and relegated to an automated mitigation system, the users may not have had as much confidence in the automated mitigation system's abilities as in their own. This finding is an important one, especially in the context of broader vehicle automation, and somewhat resonates with some of the current literature on driver acceptance of vehicle automation. The above findings are further reinforced by the trust and acceptance outcomes, where results indicated that a slightly higher percentage of drivers trusted System B as compared to System C.

Another pertinent finding related to the above was with respect to the preferences of the drivers for the auto-braking component as compared to the auto-acceleration one. Even for System B (without automation) there was a clear preference for the braking recommendation over the acceleration one. Extending this to System C, there was a higher satisfaction with the auto-braking alert appropriateness and time as compared to the auto-acceleration. Even for measures of trust in these components, the drivers had significantly higher confidence and trust in the auto-braking system compared to the auto-acceleration one. Some further driver behavior data helps to contextualize this finding. Some participants were not necessarily making response decisions as per the recommendations from the systems. There was no statistical significance for this observation, but it was more evident during recommendations of 'accelerate' that the participant would instead brake. Whereas, for the 'brake' recommendations, the participants indeed did brake. Even in System C, with automatic acceleration, some participants overrode the automated acceleration by braking, or at least by hovering their feet over the brake pedal. These findings indicate a dichotomy of user preference for automation of stopping versus increasing speed to avoid collisions.
These preferences could potentially be explained from a locus of control perspective or from a risk identification perspective. Nonetheless, this has important ramifications for the future

design of such automated assistance systems.

Another critical finding from this evaluation has to do with drivers' hazard anticipation behaviors. As explained above, hazard anticipation behaviors are higher-order skills that are the hallmark of skilled or experienced drivers and play a significant role in driving safety and crash prevention. One noted human factors concern with the introduction of driver assistance or with vehicle automation is the concept of behavioral adaptation wherein a driver may change some element of their driving behavior as a consequence of assistive technologies. While behavioral adaptations may be generally benign, there may be some negative behavioral adaptations that can have safety consequences. In this particular case, the results seem to indicate that there is indeed reduced visual scanning behavior from drivers when using these assistive systems in terms of search for external traffic elements when navigating an intersection. Additionally, there seems to be evidence of increased in-vehicle looks at the instrument panel – potentially leading to distracted eyes-off-road behaviors, another behavior with potentially negative consequences.

This study has a few limitations that should be noted. One is with respect to the age of the participants. Although our screening criteria recruited drivers aged 20-55, the mean age was about 24, indicating that the majority of drivers were under age 30. Given that studies in many fields indicate that younger people are generally more receptive to technology than older people, the findings of this study may not apply to the general population. Another important limitation is about the limited number of instances of the intersection conflicts (LTAP/OD, LTAP/LD, and SCP) that were presented to the drivers. These conflicts could actually appear in a variety of ways in real traffic situations with a diversity of intersection types, occluding factors, traffic volume, etc. Given simulator limitations and scope of the study, here the instances of these conflicts were presented in a fairly homogeneous intersection type with low traffic and all simulated during daytime dry conditions. Driver behaviors and acceptance of these systems may indeed be moderated by other external and environmental factors, something that can be further examined in future work.

8. Outputs

The following outputs were generated during the performance of this project:

- Poster presentation at the 2019 Road Safety and Simulation International Conference: Pradhan, A.K., Jeong, H., Bao, S., Jessamy, C., Novak, M., Desai, S., (2019) Simulator Evaluation of an Intersection Maneuver Assist System with Connected and Automated Technologies. Road Safety and Simulation Conference, Iowa City, IA.
- Invited panelist at Workshop titled "Using Driving Simulators to Examine User Interactions with Infrastructure Elements" at 2019 Road Safety and Simulation International Conference.

9. Outcomes

The project work generated the following outcomes:

- Concepts for intersection management assistance systems implemented in a driving simulation platform.
- Associated Human Machine Interface elements.
- Novel dataset of empirical user data collected during experimental evaluation of systems.
- One post-doctoral trainee funded.
- One MS student participation (and partial funding) inproject.
- Two undergraduate student participation (and partial funding) inproject.

10. Impacts

The impacts from this innovative research study are significant. First, the study leveraged advanced automated vehicle driving simulator, along with integrated high-resolution eye tracking capabilities, to conduct timely, relevant, and innovative human factors experimentation on connected and automated vehicle technologies. This bolsters the evidence for the use of such experimental platforms to conceptualize, prototype, and evaluate intelligent intersection management systems. The incorporation of the eye tracking system in addition provided a useful tool to examine the behaviors of drivers, especially as related to their visual gaze. The design and experimentation process also had an educational and training component with at least four students/postdocs trained on driving simulation research, and on connected and automated vehicle concepts. Second, the outcomes and results this research have significant relevance to the field and contributes important empirical data and experimental findings to the relatively sparse current state of the literature. The conceptualization and prototyping of such systems also open pathways to the development of such systems beyond the research use scenario. Third, at the research level, the study lays a framework for conceptualizing these systems and for evaluation with experimental control and rigor. In addition, the outcomes provide a roadmap and identify additional questions or gaps in the literature. For example, extending the concept to on-road vehicles and validating and evaluation on a controlled close course for replication studies, as well as extending experimentation with greater ecological validity.

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12. Appendix A – Informed Consent Form

Informed Consent Form

Title of Project: Connected and Automated Vehicle Based Intersection Maneuver Assist Systems (CAVIMAS)

1) Background Information

Dr. Anuj K. Pradhan of the University of Michigan Transportation Research Institute (UMTRI) invites you to participate in a research study evaluating the use and effectiveness of connected and automated vehicle technologies in vehicles to assist drivers in intersections. The study is funded by *the US Department of Transportation's Center for Connected and Automated Transportation.* It is being conducted by UMTRI.

First, we want you to know that being in this study is totally voluntary. You may choose not to be in the study. You may withdraw from the study at any time for any reason. If you do, you will not lose any benefits to which you are otherwise entitled.

Now we will describe this study. Before you agree to be in the study, please take time to discuss it with the UMTRI research staff member giving you this form and please feel free to ask questions or seek clarifications.

2) What is the purpose of the study?

The purpose of this study is to evaluate advanced technologies that assist drivers in certain intersections. The purpose of the appointment at UMTRI is to let you drive a virtual car in a driving simulator with this assistance system while we collect driving and other types of data.

3) What is the duration of the study?

This study will take place over approximately 90 minutes.

4) What will you be asked to do today, and as the study progresses?

After you sign this informed consent form, the study and procedures will be verbally explained to you by the researcher. You will then complete the following steps as part of study.

- You will complete a short survey (Pre-survey) about your demographics and current vehicle, and driving habit, etc.
- You will then participate in a short 5-minute practice drive in the driving simulator.
- You will then drive two longer drives in the driving simulator (about 5-10 minutes long for each drive).
- After each of the two drives, you will be asked to complete a set of surveys.

- After completing all drives, you will complete a payment form and receive your incentive.

5) Are there any benefits or risks associated with myparticipation?

Benefits: You may not receive any direct benefits from being in this study, but you may enjoy your experience with driving the simulator.

Risks: The researchers have limited the risks of being in this study. There is a chance that you may feel discomfort or get sick to your stomach while you are in the simulator. That's because there is a mismatch between visual motion cues (like seeing motion) and physical ones (like feeling motion). For that reason, we ask that you not participate if you have a history of repeated motion sickness. During the experiment we ask that you tell us at once if you feel any level of discomfort. We will stop the experiment right away. There are no penalties for stopping. As with any research study, there may be additional risks that are unknown or unexpected. The researchers have taken great precautions to ensure the safety of the participants throughout the duration of the study.

6) Will I receive any payment for participating in thestudy?

For this study, you will receive $40 at the end of your appointment. If you choose to end your participation before the study was completed, you will still be entitled to the full incentive amount.

You will be responsible for your travel to the study site. Parking will be provided.

7) What are my participation alternatives?

In order for you to be in the study, you must agree to be in the study. You may discontinue your participation at any time. You may also skip any of the survey questions for any reason.

8) What information will be recorded about me in thisstudy?

The following information will becollected:

- Name, age, and demographics information (via survey)
- Driving simulator measures (reaction time, vehicle kinematics and position)
- Eye movement (overall visual glance patterns, glances at the warning interfaces etc.)
- Survey responses
- Audio and video recordings during the experiment.

9) Will my information and study results be kept confidential?

We plan to publish the results of this study, but we will not include your name or information that could identify you in any publication. All data that we collect and analyze will be de-identified after data-collection is complete. The research team may use the video recordings (with audio included) collected in this study for teaching purposes or in presentations. We will only use your audio/video recordings for these purposes if you give us permission to do so. You may participate in the study without agreeing to let us share the recordings for these purposes.

To keep your information safe, all data will be kept securely at U-M. Video (with audio) recordings will be stored in a locked cabinet on storage devices inside of a locked office at UMTRI, or on a secure computer server protected within the UMTRI network. Only study personnel will have access to your data. After the study is complete, no information will be kept that could identify you, except for the audio/video recordings. All study data will be the property of UMTRI. They will be stored at U-M indefinitely. They may be used in the future for further analysis. Again, analyses will be of coded, aggregated data not linked to your actual identity. All study data (including audio/video recordings) from all participants may be shared with other researchers as part of current or future analyses of these data. If we share data with other researchers, it would not contain your name. If we share your audio/video recordings with other researchers we will require them to sign a confidentiality agreement before viewing the recordings. Allowing us to keep and analyze your data is required to participate.

Your data will be deleted if you withdraw before study completion.

10) What if I have further questions?

If you have any questions during this study, you may contact: Dr. Anuj Pradhan at 734-647-9191.

If you have questions regarding your rights as a research participant, or wish to obtain information, ask questions or discuss any concerns about this study with someone other than the researcher(s), please contact the University of Michigan Health Sciences & Behavioral Sciences Institutional Review Board, 2800 Plymouth Rd., Building 520, Room 1169, Ann Arbor, MI, 48109-2800, 734-936-0933, or toll free, 866-936-0933, irbhsbs@umich.edu.

Consent

By signing this paper, you are agreeing that the purpose and details of the study have been told to you. You are agreeing to take part in the study to have your driving video recorded (with audio). You will be given a copy of this paper for your records and a signed copy will be kept with the study records.

CONSENT TO PARTICIPATE

I have read the explanation about this study. I understand it. And my questions have been answered. I hereby agree to take part in it and to have my driving video recorded (with audio).

____ __________

Signature Date

____

Print Name

The research team may use the video recordings (with audio) collected in this study for teaching purposes, diagnostic purposes, or in presentations. You may participate in the study without agreeing to the use of these recordings for these purposes. Please indicate your choice by checking one of the statements and initializing below:

☐ I agree to the use of the video recordings (with audio) collected in this study for teaching and diagnostic purposes or in presentations.

☐ I do NOT agree to the use of the video recordings (with audio) collected in this study for teaching and diagnostic purposes or in presentations.

________ Initials

13. Appendix B – Screening Questions

Screening Questions:

1. Are you male or female?
    a. Male
    b. Female

2. How old are you? *[If age 20-55 candidate eligible. If age less than 20, or greater than 55, candidate not eligible]*

3. Do you have a valid, regular license? *[If no, candidate noteligible]*
    a. Yes
    b. No

4. On average, how many days per week do you drive? *[If s/he does not drive at least 2 days per week, candidate not eligible]*

5. On a scale from 0 to 3, with 0 being NEVER and 3 being NEARLY ALWAYS, how often do you experience nausea, headache, and/or dizziness (i.e., motion sickness) when (a) in a vehicle; (b) on amusement rides; (c) flying on an airplane; (d) on a boat; and, (e) in a simulator (if applicable)?

    [If any response greater than 1, interviewer collects as much info as possible in terms of current vs. past incidences, frequency, severity, symptoms, etc. Based on his history, research team will make a decision. For certain, if respondent reports a 3 to any of the items, then s/he is not eligible.]

6. Do you wear corrective eyewear?
    a. Yes
    b. No

7. If yes, do you wear glasses, contacts, or both? *[If participant has both, request that s/he wears contacts to study appointment. If only glasses, candidate noteligible.]*
    a. Glasses
    b. Contacts
    c. Both

8. Do you have any visual impairment (other than corrective eyewear)? [If visual impairment, take as much info as possible about impairment. Then tell him that you need to contact your supervisor to verify that participant is eligible.]
    a. Yes
    b. No

<u>For Female Participants Only:</u>

9. Are you pregnant? [If yes, candidate not eligible to participate].
    a. Yes
    b. No