Investigation of Autonomous/Connected Vehicles in Work Zones

Final Report
December 2021

SWZDI
Smart Work Zone Deployment Initiative

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16. Abstract

It is anticipated that autonomous truck platooning could lead to many benefits, such as maximizing existing road capacity, decreasing fuel consumption through drafting, and reducing emissions. Despite the voluminous research on truck platooning, very little has been relevant to provide guidance to departments of transportation for operation in work zones.

This study is the first research project that examined truck platooning in work zones. A networked or federated simulator was used in which a vehicle driven by a human subject encountered a truck platoon with the lead truck driven by a human driver. The experiment involved 10 scenarios composed of differences in education, truck signage, and number of trucks in the platoon.

The results point to the importance of education as the post-education vehicle speeds increased between 8.6% and 12.9% across scenarios, and the distance headways decreased between 28.8% and 30%. The vehicles increased in efficiency while still staying under the work zone speed limit.

On the other hand, the use of truck signage changed driver behavior in an arguably undesirable way by increasing the percentage of platoon bypasses. As the post-simulator survey revealed, 94% of the subjects believed it was safer not to bypass the truck platoon and yet about 34% chose to do so.

This initial investigation into truck platooning near work zones is a beginning upon which further investigations on education, signage, and platoon size policies can continue.

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INVESTIGATION OF AUTONOMOUS/CONNECTED VEHICLES IN WORK ZONES

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This research was conducted under the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(295), involving the following state departments of transportation (DOTs):

- Iowa (lead state)
- Kansas
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- Nebraska
- Wisconsin

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EXECUTIVE SUMMARY

Autonomous truck platooning refers to a system by which multiple trucks could follow a leading truck using technology such as cooperative adaptive cruise control (CACC). There are many anticipated benefits from such a system such as a shortened headway resulting in more efficient use of existing capacity and reduced fuel usage via drafting. Both governments and public agencies, and private trucking and fleets are exploring this system including the Federal Highway Administration. Since the United States relies heavily on trucking, there is great expectation that such a system can transform the current freight system.

Because truck platooning is a new technology that is being developed, there are many unknowns on its potential impacts toward surrounding traffic. Even more challenging is the deployment of such a system in work zones. Work zones could involve various atypical configurations of roadway and geometrics such as lane drops and the reduction of lane width and shoulders. It would be beneficial to investigate and anticipate potential issues in preparation of widespread deployment of such systems in the US. Some of these issues include the effectiveness of public education, the use of signage mounted on the back of trucks, and the number of trucks in a platoon.

A networked or federated simulator system was used for investigating the aforementioned issues surrounding truck platoons in work zones. The simulator system was composed of a driving simulator that allows the detailed analysis of human driver behavior. The system also involves a trucking simulator so as to replicate realistic human driving to mimic the leading truck in a truck platoon. The experiment scenarios involved a human subject driving on a lane that is to be closed while approaching a work zone. When the human subject nears a work zone, the subject will encounter a truck platoon on the open lane. The subject will then change to the open lane while deciding to bypass the platoon or to follow the platoon until the human subject traverses the work zone. Table ES-1 shows the 10 scenarios encountered by each human subject in the experiment.

Table ES-1. Simulator scenarios

Scenario	Education	Number of Trucks	Sign	Order
1	No	2	No	Randomized
2	No	4	No	
3	No	2	Truck Platoon	Randomized
4	No	4	Truck Platoon	
5	No	2	2 Trucks	
6	No	4	4 Trucks	
7	Yes	2	Truck Platoon	Randomized
8	Yes	4	Truck Platoon	
9	Yes	2	2 Trucks	
10	Yes	4	4 Trucks	

These scenarios involve lack of or the delivery of education, having 2 or 4 trucks in a platoon, and three different sign options of no sign, "Truck Platoon", and "# of Trucks." Figure ES-1 shows an example of a type of truck signage that was investigated in this study.

Figure ES-1. Example of truck signage

This research project was delayed due to the COVID-19 pandemic. Just as the simulator system was being readied for hosting human subjects, the entire laboratory was shut down as per public health and University directives. Eventually the pandemic restrictions were lessened, and it became possible to recruit human subjects and conduct the study. Despite the public hesitation about socializing, a full set of human subjects was successfully recruited.

The data for the simulator experiment involved vehicle speeds, headways, and lane position. The data points of note were the speeds and headways of vehicles when merging from the closed to the open lane and when it passed the work zone taper. A record was kept of whether a human subject tried to bypass the truck platoon or remained behind the platoon. Statistical analysis was performed to ensure that results were due to system trends and not random variations. Table ES-2 shows an example of the types of data used in analysis.

Table ES-2. Example of simulator results involving education and truck signage

			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
No Education	Follow	Mean	38.30	1034.42	41.62	901.24	40.88	898.59
	Bypass	Mean	47.43	-670.79	48.36	-556.24	47.75	-497.42
Education	Follow	Mean	-	-	44.77	752.77	43.43	708.10
	Bypass	Mean	-	-	49.38	-462.86	53.00	-456.33

For example, the table shows a consistent trend where the use of signage resulted in increased speeds and decreased headways for vehicles that followed the platoon.

Some noteworthy quantitative results and analysis are as follows. The use of education resulted in a 12.9% increase in speed and a 30% decrease in headways for the two-truck platoon and an 8.6% increase in speed and a 28.8% decrease in headways for the four-truck platoon. Thus, regardless of the number of trucks in a platoon, education led to an increase in speed even though the speeds are still around the work zone speed limit of 50 mph. And education led to a decrease in headways. One interpretation is that knowledge of truck platooning leads to drivers driving more efficiently through the work zone. The use of truck signage resulted in a 6.4% to 17.8% increase in the number of vehicles that bypassed the platoon. Thus, drivers understood the truck signage and acted in an, arguably, undesirable fashion. But despite the increase in the percentage of bypassing vehicles, the knowledge of the platoon might prevent drivers from cutting into the middle of a platoon. There was no significant vehicle cut-in data from this experiment to validate this hypothesis. It was interesting to analyze the increase in bypassing in conjunction with the post-simulator survey results. It is revealing that 94% of the subjects believed that it was safer to follow than to bypass and yet 34% replied that they would nonetheless choose to bypass, as was found in the driver behavior in the simulator experiment. Going back to the issue of education, it would be important to not only educate on the meaning of a truck platoon but also how to drive safely near a platoon especially in the context of work zones. In terms of the type of sign message, “Truck Platoon” versus “# of Trucks,” there was no significant difference in driver behavior; although 78% of the subjects preferred the “# of Trucks” sign.

Despite the voluminous research on truck platooning, very little has been relevant to providing guidance to departments of transportation for operation in work zones. This study provided some initial guidance from which further investigations could proceed. One such direction is the design and development of effective educational material that could promote safe and efficient driving near platoons. Another direction is the continued exploration of the use of truck signage to improve safety and efficiency. A third direction is to further investigate the tradeoffs in the number of trucks and to develop policies and guidelines that would balance logistical needs with work zone operations.

1 INTRODUCTION

Autonomous vehicles, and specifically truck platooning, have the potential to result in many benefits such as energy savings via drag reduction, increased capacity via shorter headways, improved safety from faster reaction times, and increased comfort and productivity for drivers. Partially Automated Truck Platooning, a low form of automation (SAE level 1) is expected to be widely deployed in the near future. But many unanswered questions surround the deployment of truck platooning near work zones stemming from the interactions with human-driven vehicles. For example, it is uncertain how human drivers will react while encountering truck platoons, especially near work zones. Also, fatal crashes involving trucks occur at a higher percentage at work zones compared to non-work zone locations, as shown in Table 1-1.

Table 1-1. Fatal crashes involving large trucks

Crash Type	All Fatal Crashes	Work Zone Fatal Crashes
Involved at Least One Large Truck	11.20%	23.60%
Involved a Large Truck and Two or More Vehicles	16.90%	32.60%
Involved a Large Truck That Was Parked/Working	4.10%	18.90%

Source: FMCSA 2014

Because of these behavioral and safety issues, it is helpful to research such issues near work zones to help DOTs prepare for the arrival of truck platoons.

Transportation simulators allow the testing of human subjects in a safe, controlled environment. They are widely used to conduct research on safety, geometric design, and traffic operations. Due to the rapid development of affordable computer technology, improvements in visualization and motion systems, the quality of transportation simulators is steadily increasing. Multi-modal simulators, such as driving, bicycling, and pedestrian simulators have proven to be valuable tools for investigating human factors in transportation (Chrysler et al. 2015, Fisher et al. 2011, Karamouzas et al. 2009, O'Hern et al. 2017, Wang et al. 2010).

To date, most simulator studies use a single simulator and focus on an individual driver, bicyclist or pedestrian in a specific scenario (Lehsing et al. 2015). The participants are only exposed to programmed (static or dynamic) actors not replicating the broad range of human behavior. However, human behavior is highly dependent on communications and interactions with other road users, and interactions are hard to be pre-scripted. Therefore, there is a need for federated simulators and several studies in the recent past used the simultaneous, synchronous simulation approach to analyze advanced driver assistance systems and the interaction of multiple drivers (e.g., Rittger et al. 2015).

The integration of multimodal simulators enables the reproduction of a controlled, more complex and potential hazardous environment. For example, federated simulators can connect driving, bicycling, walking and wheeling simulators, allowing them to interact within one virtual world. The interactions offer insights into how road users make decisions when interacting with other travelers in realistic contexts (Hancock and de Ridder 2003). Federated simulators can also be used as a testbed to examine the reliability and potential benefits of new Smart Cities technologies and Connected/Autonomous Vehicles (CAVs). In addition, federated simulators can involve users at different physical locations representing a more diverse base of participants.

Driver behavior near a work zone lane drop involves both the behavior of platoon truckers and the surrounding vehicles. Truckers will decide on how best to disengage from the platoon and merge onto the open lane(s), while surrounding vehicles react to the truck platoon and find ways to merge. The analysis of driver behavior obtained from the detailed output of federated trucking and driving simulators can provide insights into driver behavior while reacting to realistic truck driving.

As DOTs are owners and operators of roadways, they are instrumental in the development of rules and regulations governing driving near work zones. As public servants, they are faced with juggling various important public policies. These include the promotion of freight movement and its relationship to national economic vitality, traffic and worker safety, congestion relief and travel reliability, and environmental sustainability. Research can aid in the formulation of rules and regulations by informing the potential tradeoffs of implementing certain policies.

This report documents the results from a federated driving simulator study that helped to answer some practical questions related to the deployment of truck platoons near work zones. The specific questions addressed are: (1) How important is public education in producing desired behavior for drivers near truck platoons at work zones? (2) Does signage on the back of trucks help improve following driver behavior? (3) How does the number of trucks in a truck platoon impact driver behavior? Several other related questions are also investigated via a post-simulator survey.

2 LITERATURE REVIEW

2.1 Truck Platooning Literature

At first blush, there appears to be an overwhelming amount of literature on truck platooning. A technical library search on the term "truck platooning" yielded 426 records. The extensive literature reflects the massive efforts in truck platooning throughout the world and especially in North America, Europe, and Asia. For such a disruptive technology necessitates the investigation of a wide range of issues. But a closer look reveals that certain topics are well-worn while the topics addressed in this research have not been explored previously. Some of these well-worn issues include truck platoon control algorithms, efficiency savings, wireless communications, transportation system considerations, logistics, impacts on infrastructure, and human factors. But on the issue of truck platooning in work zones, there has hardly been any research. The following sections paint an overall picture of truck platooning literature without diving into details since most of the literature are not on point with respect to the topic at hand.

It is unsurprising that so much focus has been on control algorithms or the method by which trucks could automatically follow a leading truck driven by a human. For the adoption of such a technology hinges on the existence of a control algorithm that would be safe, stable, and efficient. The following are some recent examples of the types of research being conducted on the topic of truck platooning control. Earnhardt et al. (2021) proposed a platoon formation/splitting control algorithm by using a velocity trajectory optimization (VTO) approach. Schirrer et al. (2020) focused on the use of a multi-rate explicit model-predictive controller to improve safety during emergency braking of truck platoons. Saeednia and Menendez (2017) used a cooperative distributed approach using consensus algorithms for the formation and modification of platoons. Bijlsma and Hendriks (2017) focused on the fail-safe requirements for truck platooning in level 2+ systems. Zegers et al. (2017) designed a multi-layer approach to Cooperative Adaptive Cruise Control (CACC) to ensure that desired positions are maintained while attenuating disturbances. Larsson et al. (2016) produced a broadcast message forwarding algorithm aiming to reach all nodes in the platoon with as few forward messages as possible. As the examples show, truck platooning is complex and encompasses multiple challenges such as how to form platoons and split them up, improve safety, deal with subsystem failures, minimize oscillations, and coordinate among multiple trucks.

Another major focus of recent research has been on examining the potential efficiency gains from truck platooning. Not only is truck platooning expected to increase capacity via shorter headways, it is also expected to result in better fuel economy via drag reduction through drafting. The following are some examples of research on efficiency. Borhan et al. (2021) employed SAE J1321 procedures to investigate truck platooning under real-world driving conditions. The test found that despite the potential for improved efficiency that platooning could result in increased fuel consumption under high traffic or on high grades. Van De Hoef et al. (2019) developed a predictive framework to improve platoon formation with the goal of reducing fuel consumption. Zhang et al. (2018a) surveyed the literature on the possible improvements in fuel economy from truck platooning. The large number of publications on truck platooning efficiency show that the subject is the major motivating factor behind the deployment of commercial truck platooning.

Some researchers focused on the communications aspects of the connected and autonomous vehicle technology. Elhaki and Shojaei (2021) investigated the problem of truck platoon control under limited communication range. Adam et al. (2021) examined various issues related to Dedicated Short Range Communications (DSRC) in truck platooning such as occlusion, moisture in the air, elevation and antenna position, interference, and road curvature and grade. Vukadinovic et al. (2018) studied the performance of truck platooning using different vehicle-to-vehicle (V2V) technologies. These examples illustrate some of the challenges related to connected vehicles as well as the performance as a function of communications technology.

Many researchers investigated the impacts of truck platooning on physical infrastructure. Sharma et al. (2020) studies the effects of truck platoon collisions on concrete barriers. They employed the Manual for Assessing Safety Hardware (MASH) Test Level 5 in their simulation of multiple impacts from a truck platoon. Thus, a truck platoon potentially acts as an aggregate in a crash scenario. Gungor et al. (2020) investigated the potential decrease in pavement longevity due to truck platooning because of the channelized load application which hinders the healing properties of asphalt concrete. They optimized a daily lateral control strategy that improves pavement life. Thulaseedharan and Yarnold (2020) examined the effects of potential truck platoon loading on concrete bridges in Texas. They studied the factors such as truck type, truck spacing, number of trucks within a platoon, original design methodology, and bridge span length. And they produced guidance on operations and regulations in light of these factors. These examples involved infrastructure-related issues, including safety, pavement longevity, and bridges.

Significant research has been conducted to examine how truck platoon traffic affects transportation networks, i.e. system considerations. Pasquale et al. (2018) characterized truck platoons as moving bottlenecks. They proposed a control scheme in which platoon speed is set according to surrounding traffic conditions to minimize overall traffic congestion. Saeednia and Menendez (2016) used variational theory to evaluate the traffic conditions for the system-wide deployment of truck platooning and to produce a decision support system. Deng and Ma (2014) utilized optimal control theory to determine an efficient speed control algorithm for platooning. Similarly, several researchers focused on logistics and freight issues in analyzing transportation networks. Haas and Friedrich (2021) used simulation to investigate city-logistics using platooned delivery vans. The authors found that increasing the platoon number can decrease waiting time but increases intersection delay. Elbert et al. (2020) used an agent-based simulation model to investigate decentralized truck platooning and the tradeoff between wait times and platoon savings. You et al. (2020) explored the use of truck platooning for solving the local container drayage problem (LCDP). LCDP refers to the transport distance between a local terminal and the customer which is short compared to the container packing and unpacking time. The examples above illustrate the system issues related to truck platooning. These system issues relate to normal travelers that share the transportation network with truck platoons. These issues also relate to logistics and freight, or the transport of goods.

Several researchers worked on human factors in truck platooning. Harre and Feuerstack (2018) focused on Human Machine Interface (HMI) issues. Specifically, they investigated human operator monitoring of safety-critical systems and the use of heuristics to estimate relative perception accuracy and reaction time. Neubauer et al. (2020) examined the issue of truck driver acceptance and found hesitancy with regards to level 1 platooning. Castritius et al. (2020) investigated truck platooning acceptance of German commercial drivers and found a clear increase in acceptance once they have experienced platooning on the Autobahn. Castritius et al. (2021) studied the issue of driver situational awareness and sleepiness using eye tracking data. The authors found that sleepiness did not increase under semi-automated platoon driving. Even though the current research also concerns human factors, the focus is on the behavior of drivers near platoons as opposed to the drivers in truck platoons. Truck drivers are commercially licensed and trained and their behavior might not correspond to drivers of passenger vehicles.

There were two sources that had some connection with the present project, albeit remote. Even though Duret et al. (2019) do not mention work zones explicitly, the scenario they addressed of network discontinuities could apply to lane closures that are common in work zones. The authors investigated a truck platoon splitting algorithm near discontinuities using bi-level control. The current project also concerns truck platooning near lane closures. Zhang et al. (2018b) investigated the issue of following trucks being heavily blocked in their front view because of the short headways in a truck platooning situation. The authors conducted a driving simulator experiment using 22 subjects and found positive effects of a see-through technology which is when a lead truck has a screen at its rear projecting its front view. The current project also involves a driving simulator study and is concerned with driving behavior near truck platoons. However, neither study address directly issues of concern to state DOTs for the operation of work zones. The fact that out of 426 sources, only two has a limited connection to the current project, demonstrates the uniqueness of the current project.

As shown in this literature review, previous research has not addressed the issues of truck platooning driver education, truck platoon signage, and the effect of the number of trucks in a platoon on nearby drivers. Such original questions are important in formulating policies and guidelines for the operation of truck platoons near work zones. Work zones are atypical driving environments and adding truck platoons increases the complexity for drivers.

2.2 Psychophysics and Biofeedback Utilization

The use of psychophysiological devices for driving simulator studies is not widespread or standardized. Therefore, it is useful to investigate the existing literature in order to explain the effects in the use of such devices in this research. Biofeedback is a mind-body technique for mental and physical intervention (Frank et al. 2010). Individuals learn to modify physiology to modify physical and mental states. For example, biofeedback training provides conditioning and feedback learning to improve user behavior, and psychophysiological psychotherapy is useful for reducing stress. Biofeedback is divided into two modalities: peripheral and central. Peripheral biofeedback is based on electromyography, electrodermal response, heart rate, temperature, or blood volume pulse. Central biofeedback is based on electroencephalography neurofeedback. Both types of feedback could be used to improve concentration and attention and lower anxiety and disruptive mental chatter (Pop-Jordanova and Gucev 2010).

There are six popular types of biofeedback sensors: (1) eye tracking, (2) Facial Expression Analysis (FEA) (3) Electrodermal Activity (EDA)/Galvanic Skin Response (GSR), (4) Electroencephalography (EEG), (5) Electrocardiogram (ECG/EKG), and (6) Electromyography (EMG). Eye trackers monitor eye/pupil position and movement to assess visual attention and to monitor a user's focus at any given time. There are three types of eye trackers. Screen-based eye trackers monitor where a user focuses on a screen location, eye-glass-based trackers point one camera at the pupil and one of the subject's field of view, and VR trackers monitors a user's attention on the virtual world. FEA assesses emotions via facial coding systems. EDA/GSR measures stress level, typically via fingertips, by measuring heightened skin conductance, as shown in Figure 2-1.

iMotions.com 2019

Figure 2-1. Example of EDA/GSR device

EEG monitor, typically in the form of a head band or a full cap, records brain waves as shown in Figure 2-2.

iMotions.com 2019

Figure 2-2. Examples of EEG devices

ECG/EKG represents the series of electrical signals in the heart. EMG represents the muscle response or electrical activity in response to the stimulation of the muscle.

2.3 Application of Empatica E4 Device

The Empatica E4 Device was used in this project. The E4 is a device worn on the subject's wrist that measures the following psychophysical parameters: electrodermal activity (EDA), blood volume pulse (BVP), heart rate (HR), skin temperature, and acceleration (Empatica 2018). EDA is a measure of arousal in the sympathetic nervous system and is correlated with sweat secretion. EDA is measured with two electrodes on the device's wristband that measure skin conductivity on the inner wrist. Stress response is characterized by a fast change in EDA signal in response to a single stimulus followed by a recovery period, known as skin conductance response (SCR) (Setz et. al. 2010). Non-specific fluctuations (NS.SCRs) in EDA signal may also occur spontaneously and are not related to a single stimulus. NS.SCRs may also be considered measures of psychophysiological activation due to stress (Bari 2019). BVP is a measure of variation in the volume of arterial blood under the skin. BVP is measured using photoplethysmography (PPG) sensors, placed on the outer wrist. BVP may be used to derive other parameters but is itself indicative of stress (Handouzi et. al. 2014). Peak-to-peak amplitude in BVP signal decreases when the body is in a state of alert, such as during activation of the sympathetic nervous system in times of stress. Inter beat interval (IBI) decreases during times of stress. The E4 device derives its HR measure from IBI, which is obtained from BVP measurements. Skin temperature is measured using an infrared thermopile on the outer wrist. Acceleration of the subject's wrist is measured with a 3-axis accelerometer located inside the device (Empatica 2014).

Studies have assessed the Empatica E4's measurement accuracy against other devices, like an ECG, designed to measure the same heart rate characteristics. McCarthy et. al. (2016) compared the E4 PPG data with ECG data and found that both devices had the same quality of data 85% of the time. In the study, the E4 yielded poor data more often than the ECG device. The study noted that the poor data may be due to the E4 being worn on the subject's wrist, causing more motion of the device than the ECG on the subject's chest. Ollander et. al. (2016) also compared the E4 to an ECG device in laboratory tests and found a significant loss in IBIs from the E4, particularly when the subject was performing a task. However, this study also reports that the mean heart rate and standard deviation of heart rate are acceptably measured by the E4. The same study also compared the E4 EDA measurement to skin conductivity sensors placed on the subject's fingertips and found the E4 EDA sensor to be more discriminating than the lab device. A study used machine learning on all psychophysical parameters measured by the E4 and was able to detect 70% of total stressful events with 95% precision (Gjoreski et. al. 2017). The study utilized an activity recognition classifier to identify periods of activity from the E4 acceleration data and discriminate between stressful events and active events that may exhibit psychological arousal similar to stressful events. Without the use of the activity classifier, stress detection precision was reduced to 7%.

Several studies have used the E4 device parameters to measure stress level in subjects. Stress monitoring on drivers has been performed using ECG, EMG, skin conductance, and respiration (Healey and Picard 2005, Rodrigues et. al. 2015). Healey and Picard distinguished three stress categories with 97% accuracy and found that skin conductivity and heart rate metrics are the most closely related to driver stress. Sierra et. al. (2011) using heart rate and galvanic skin response, which is closely related to EDA and skin conductivity, developed a stress detection system with 99.5% accuracy. Heart rate metrics and EDA may also be used separately to detect stress with high accuracy. Setz et. al. (2010) used only EDA data to discriminate stress with 82.8% accuracy, examining EDA signal peak height and instantaneous peak rate. Handouzi et. al. (2014) used only BVP data to recognize anxiety, examining three characteristics: moving average of IBI, moving average of peak-to-peak amplitude, and power spectral density. The study was able to detect two emotional states of anxiety (anxious vs. not anxious) with 97% accuracy. The individual BVP features performed at least 70% accuracy. Given the results from the literature, it appears that the E4 could be used to assess human subject stress during the simulator study. As will be discussed later, the E4 device did not function as expected during the simulator trials. The possible reason for the problem was due to the motion of drivers steering the vehicle. Even when a vehicle is not switching lanes, driving involves constant adjustments in steering to stay somewhat centered in the driving lane. The use of the E4 device was not within the formal scope of work. The researchers were hoping that the E4 data could have provided additional value to the research.

3 HUMAN SUBJECT STUDIES

3.1 Approval Process

An Institutional Review Board (IRB) is an entity, often part of a university, that reviews research proposals for human subject experiments. IRBs were established in 1974 by the Department of Health Education and Welfare to promulgate the regulations on the protection of human subjects. An IRB reviews the conduct of research to ensure that federal and local regulations, and ethical principles are followed.

The IRB review process involves the submission of an extensive set of materials. The most important IRB materials are contained in Appendices A through F. They are the official IRB approval letter, post-simulator survey, simulator sickness questionnaire, research protocol, recruitment flyer, and consent form. IRB also coordinates closely with accounting and information systems to ensure financial accountability, and data privacy and security. The IRB weighs the risks and benefits of the research, issues modifications to the research, and approves if all concerns have been addressed. After a study has been approved for experimentation, the IRB continues to require researchers to monitor and report any issues. At the completion of the study, researchers are required to submit a final report to IRB confirming that proper procedures and protocols were followed throughout the study.

The human subject study protocol is a comprehensive document that describes the proposed research in sufficient detail so that IRB staff can adequately address any human subject concerns. The research purpose and objectives must be clearly presented. In this project, the purpose is to investigate how drivers behave while encountering truck platoons near work zones. The appropriate scientific rationale needs to be provided. In the near-term scenario where truck platoons must share the road with human-driven vehicles (HDVs), truck platooning has the potential to impact operations near work zones and/or near entrances and exits on access-controlled highways. Depending on the length of platoons (e.g., two or more), there are different ways in which driver behavior could impact safety and efficiency near work zones. Despite the body of literature examining truck platooning, none has investigated the impact of platooning near work zones. The recruitment process needs to be described clearly, such as how and where will recruitment occur. The relevant communications materials for truck platoon study recruitment (e.g., flyer, email) were submitted to IRB. A key concept in ethical human study participation is the concept of informed consent. This concept involves subjects who are both willing participants and well-informed participants. The consent form and the description of the consent process were submitted to demonstrate the adequacy of the consent process. IRB carefully reviews the population from which human subjects are drawn. For this study, only Missouri-licensed adult drivers qualify for participation. The study design must be described in detail. For the simulator study, the entire human subject trial is detailed, including the orientation, informed consent process, simulator warm up, simulator trial, post-simulator survey, and de-briefing.

An important part of the protocol evaluation is the balancing between potential risks and benefits. Managing risk is an integral part of human subject studies as there are always risks whenever human subjects are involved. Thankfully, simulator studies typically involve relatively mild risks. Typically, there is a small percentage of the subjects who experience discomfort or simulator sickness. Simulator sickness is not well understood by the medical community even though some hypothesize that it is similar to motion sickness and may be caused by vection, which is a mismatch between visual and motion cues received by the body. A longer study increases the risk for simulator sickness. Thus, this study was kept under 20 minutes of actual driving time and limited to 10 scenarios. Additional mitigation strategies including controlling the testing environment (e.g., cool temperature and multiple fans) and careful monitoring of human subjects. There were not any subjects that dropped out for this project, but there has been a few other ZouSim studies where subjects did not feel well and had to drop out of the study after completing a few scenarios. The benefits of this simulator study are potentially great and could benefit all Missourians. The knowledge gained for improving work zone operations statewide which are encountered by millions of Missourians far outweigh any potential discomfort experienced by the 30 human subjects.

In order to incentivize human subject participation, researchers typically offer compensation. Here, $20 gift cards were issued to the participants. As with the handling of other financial aspects of research grants, there are several steps that were taken to ensure financial accountability for our grantor, the Smart Work Zone Deployment Initiative pooled fund. Gift cards were kept in a locked office accessed by a custodian. IRB requires that strict records be kept of the issuing of gift cards even for a small denomination. The names and addresses of the compensated party were submitted to accounting. Due to the small denomination, a waiver was issued by accounting to forgo the recording of the social security numbers of the subjects.

3.2 Data Privacy and Data Management

The protection of the privacy of participants is required for human subject studies. This is true even if an unauthorized release of data is not particularly embarrassing or harmful. Here, the videos of human subjects driving through work zones or survey answers do not contain embarrassing details. The ZouSim data management plan includes the following components. First, no personally identifiable information is stored in the data files such as the simulator videos, derived data, and surveys. A unique identifier was assigned and used to link the participant data with the participant. The hash table linking participants with unique identifiers was locked in a locker inside the ZouSim laboratory. At the completion of each research day, data was compiled and locked inside the ZouSim laboratory. All the steps taken minimize the potential for any data breaches.

3.3 Complications Due to COVID-19

The COVID-19 pandemic caused major disruptions to the research project. Just when the ZouSim lab was readying for human subject trials, national, state, and local restrictions started to appear. These health restrictions shut down the entire University and specifically the ZouSim lab. Computing equipment was relocated off campus, but the driving simulator vehicles could not be accessed for several months. The shutdown delayed various steps in the research including design and testing of the simulator scenarios, the calibration of the hardware for this experiment, alpha (or in-house) testing, and the human subject trials. There were additional procedures mandated by COVID rules such as social distancing, mask wearing, and cleaning of frequently contacted surfaces such as the steering wheel and door handles. With the easing of the pandemic restrictions, the conduct of human subject studies became possible even though there was still a general hesitancy of the population to participate in human subject trials. After extensive recruiting efforts in Missouri, the required number of subjects was attained.

4 SIMULATOR EXPERIMENT DESIGN

4.1 Description of ZouSim Simulator

This simulator study utilizes the ZouSim driving simulator. ZouSim is a suite of networked transportation simulators that allows the safe and effective investigation of various transportation modes, including the interaction among multiple modes. Figure 4-1 shows the ZouSim driving simulator, and Figure 4-2 shows the ZouSim heavy truck simulator.

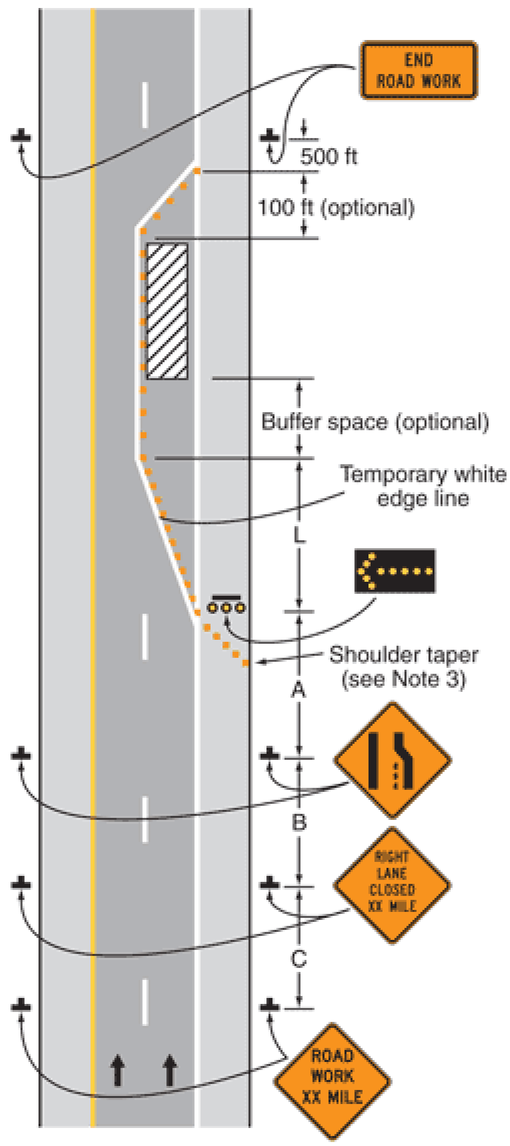
Figure 4-1. ZouSim driving simulator

Figure 4-2. ZouSim Volvo heavy truck

Both the driving and trucking simulators are medium-fidelity simulators; one built around the half-cab of a Toyota sedan and the other built around the cab of a Volvo heavy truck. The active instrumentation in the vehicles includes a force-feedback steering wheel, brake and acceleration pedals, turn signals, and engine vibration generator. The ZouSim simulator environment has been used for various projects sponsored by agencies such as the FHWA, MoDOT, the FAA, and the City of Columbia. ZouSim has been utilized extensively for examining work zone safety and efficiency issues. Examples of recent ZouSim work zone studies include the use of green lights on truck mounted attenuators (Brown et al. 2018, Zhang et al. 2019), automated flaggers (Brown et al. 2018), and alternative work zone signage (Edara et. al. 2019). Other examples of recent ZouSim experiments include bicycle signage and markings (Sun and Qing 2018), geometric design of J-turns (Sun et al. 2017), autonomous vehicle interactions with pedestrians (Qing et al. 2019a), and wheelchair accessibility at airports (Qing et al. 2019b).

4.2 Experiment Scenario Design

The work zone and road section designed for the study is a two-way four-lane divided highway with a closure on the right lane. The work zone follows the MUTCD (FHWA 2009) Typical Application 33 which is a stationary lane closure on a divided highway. Figure 4-3 shows the diagram of the basic layout and signage.



FHWA 2009

Figure 4-3. MUTCD Typical Application 33

The road is intentionally designed straight so that road curvature does not influence driver behavior. Also, the road is designed as a typical Missouri highway without replicating an actual road section; the non-descript nature of the road is intentional to prevent human subjects from using their memory of actual roadways to influence their simulator behavior. A human subject starts in the right lane while approaching a work zone involving a right lane closure. As the subject-driven vehicle approaches, a truck platoon appears on the left lane with the leading truck driven by a research assistant. The human subject would then decide when to merge to the open lane and whether or not to overtake the truck platoon before merging. There could be three types of potential driver behavior in this situation: car driver slows down and follows platoon to pass the work zone; car driver speeds up and bypass the platoon before encountering the work zone; car driver squeezes in between the platooned trucks.

Table 4-1 shows the 10 scenarios presented to participants during the simulator study.

Table 4-1. Simulator scenarios

Scenario	Education	Number of Trucks	Sign	Order
1	No	2	No	Randomized
2	No	4	No	
3	No	2	Truck Platoon	Randomized
4	No	4	Truck Platoon	
5	No	2	2 Trucks	
6	No	4	4 Trucks	
7	Yes	2	Truck Platoon	Randomized
8	Yes	4	Truck Platoon	
9	Yes	2	2 Trucks	
10	Yes	4	4 Trucks	

Each participant completed all ten scenarios unless the test was unable to be completed. Scenarios were randomized to avoid sequence bias, also known as learning bias. Education refers to the experiment host explaining to the human subject the meaning of truck platoon and the signage. The following script was read to each human subject.

"A 'platoon' means that a team of vehicles are travelling together, and they interact with each other within the platoon. A truck platoon means these trucks are moving together as a team. The display on the back of the trucks indicates either trucks are in a platoon, or the number of trucks in this platoon."

A standardized script was used in order to ensure uniformity in the information delivered to each human subject.

It is important to note that certain scenarios are always presented before others. For example, "No Sign" scenarios 1 and 2 are always given to participants first. The concern is that once the subjects have seen the signage, they will retain the mental picture of the signage. Post-education scenarios come after all pre-education scenarios were completed. Again, the concern is that once a subject has been educated, that subject would retain that knowledge. The "No Sign" scenarios were not presented again post-education. The reason for eliminating those scenarios were two-fold. First, it would be difficult to ascertain the portion of the behavior that was due to education versus signage. Second, the number of scenarios had to be kept at a reasonable number in order to avoid potential simulator sickness and these scenarios were the least informative out of all the scenarios.

A screen capture of the different types of signage scenarios are discussed as follows. Figure 4-4 shows a truck platoon when no signage is displayed on the back of trucks.

Figure 4-4. No signage

Figure 4-5 shows the number of trucks in the platoon displayed on the back of trucks.

Figure 4-5. “2 Trucks” and “4 Trucks” signage

Figure 4-6 displayed the words “Truck Platoon” instead of showing the number of trucks.

Figure 4-6. “Truck Platoon” signage

There are three reasons why the display monitor was located in the middle of the right side of the back of trucks. (1) Eye tracker was utilized in the experiment; a small monitor helps researchers determine if participants were looking at a specific place. (2) The work zone had a right lane closure. Truck platoon starts on the left lane and car starts on the right lane. Putting the sign on the right side could help participants see the contents easier. (3) The size of the display was an educated guess of what would actually be deployed by trucking fleets. Larger displays would be costly while smaller display would be not as visible from distance. Display manufacturers such as Samsung have experimented with the concept of a “see through” display that covers the entire back of the truck. The concept is to provide greater safety to following vehicles. Therefore, there are potentially many forms in which messages could be displayed to nearby vehicles. Currently, there are no standards or specifications for such displays.

4.3 Human Subject Sampling

Participants of the study were adult drivers and were recruited through flyers, word-of-mouth, and individual invitations. Thirty-two human subjects participated in the simulator study. None of the participants ended the experiment early. Two scenarios across two different participants were unable be completed due to technical malfunction. Eye-tracking data was unavailable for 29 scenarios across four different participants. Driving data could not be collected from five scenarios from one participant. Eye-tracking data and/or driving data that could still be collected from incomplete scenarios was kept and analyzed. All data from one participant was excluded entirely due to poor playback quality; however, the experiment itself had no issues and the participant was given the post-simulator survey. Despite the challenges for human subject recruitment that was presented by the COVID-19 pandemic, participants represented a fairly diverse population with respect to age and gender. The age distribution was 28% for ages 18 to 25, 44% for ages 26 to 40, 9% for ages 41 to 55, and 19% for ages 56 to 70. The age distribution is skewed towards younger participants. Approximately 53% of participants were female. 84% of participants claimed to be unfamiliar with truck platoons before the study.

4.4 Description of Experiment Data

Seven measures of effectiveness (MOEs) were captured from the simulator trials. MOE 1 is driver behavior. MOE 2 is the distance between work zone and car when it merges (in feet). MOE 3 is the speed of car when it merges (in mph). MOE 4 is the distance between car and the back of the last truck in the platoon when the car merges (in feet), if the car followed the truck platoon to the work zone. MOE 5 is the distance between car and the head of the leading truck in the platoon when the car merges to the open lane (in feet), if the car speeded up and bypassed the truck platoon. MOE 6 is the record of braking of the car. MOE 7 is record of blinker use by the car.

A post-simulator survey was administered to collect participants' demographic information and obtain their preferences. The survey also asked for participants' opinions about the effectiveness of education and whether or not the signage/message conveyed information clearly and effectively. Simulator fidelity was also examined, followed by a standard simulator sickness questionnaire (SSQ) (Kennedy et al. 1993). The post-simulator survey is included as Appendix B and the SSQ as Appendix C.

As previously discussed, additional psycho-physiological data were collected that was outside the scope of the original proposal. These discussions are included to inform the readers of the attempt by the researchers to obtain additional value from the research experiment. An eye tracker tracks the movement of a participant's pupil, capturing the frequency and time of participants looking at specific spots. Due to the nature of the experiment with vehicles traveling at highway speeds, the eye-tracking and psycho-physiological data did not provide definitive insights. The eye-tracking data did provide general validation that subjects did glance at the signage on the back of trucks. The psycho-physiological data did not reveal a clear indication of added stress from certain scenarios.

5 SIMULATOR AND SURVEY RESULTS

The analysis of the experiment results will proceed as follows. First, the results from the driving simulator experiment will be presented. This presentation will merely be a description of the data; the practical significance of the results will be examined in the discussion and conclusion section. The simulator result is the most significant portion of this study. Second, the results from the post-simulator survey will be presented. The survey complements the simulator results by asking participants questions about their preferences. In the next chapter, Discussions and Conclusions, the various results presented in this section will be analyzed as a whole by integrating both simulator and post-simulator results. The next chapter will present the overall picture from this research study and the practical implications.

Statistical testing was performed. The p value is the significance level or the reciprocal of the confidence level; for example, p=0.05 means 5% significance or 95% confidence. The lower the p value, the greater statistical confidence that the results are due to systematic changes and not just randomness. The values in tables were the statistical confidence and 95% or greater are highlighted in bold face.

5.1 Driving Simulator Results

Table 5-1 shows the total number of times participants chose to either bypass or follow the truck platoon before reaching the work zone.

Table 5-1. Number of follows and bypasses

		2 Truck		4 Truck	
		Count	**%**	**Count**	**%**
No Education	Follow	56	65.9%	58	64.4%
	Bypass	29	34.1%	32	35.6%
Education	Follow	39	67.2%	43	71.7%
	Bypass	19	32.8%	17	28.3%

No participant tried to squeeze in between platooned trucks in any of the tested scenarios. The Table is sorted between two independent variables: level of education and number of trucks. The results show that there is no large difference between the number of follows and bypasses between treatments. However, in all cases, participants followed the truck platoon more often than bypass. The highest percentage of following the platoon is from the case of post-education with a four-truck platoon. This result is intuitive as drivers who are educated about truck platooning would choose not to bypass a four-truck platoon before reaching a work zone. This is some evidence for the effectiveness of education in helping drivers to make a safer choice when encountering a longer truck platoon.

Simulator results for the car speed and distance between the car and truck platoon, for measurements taken as the car passed the work zone, are shown in Table 5-2 and Table 5-3. A negative value in car-truck distance indicates that the car driver is ahead of the truck platoon meaning that the human-driven vehicle has bypassed the truck platoon. Participants could freely choose to follow or bypass between scenarios. Table 5-2 shows the comparison between no-education and education.

Table 5-2. Level of education results comparison

			2 Truck		4 Truck	
			Car Speed (mph)	**Distance (ft)**	**Car Speed (mph)**	**Distance (ft)**
No Education	Follow	Mean	39.27	933.71	39.26	943.02
	Bypass	Mean	47.10	-611.45	56.25	-315.69
Education	Follow	Mean	**44.33**	**653.08**	**42.63**	891.60
		% Difference	**12.90%**	**-30.06%**	**8.58%**	-5.45%
		p-value	**0.000**	**0.002**	**0.038**	0.343
	Bypass	Mean	51.00	-435.53	59.35	-279.59
		% Difference	8.27%	-28.77%	5.52%	-11.44%
		p-value	0.074	0.103	0.116	0.383

With no education, the average following speed was 39.27 mph and the average distance was 933.71 feet for scenarios with two trucks. Education resulted in a 12.90% (p=0.000) increase in speed and a 30.06% (p=0.002) decrease in distance in the two-truck platoon scenarios. For scenarios with four trucks, the average following speed was 39.26 mph. In the four-truck scenarios, post-education car speed also increased by 8.58% (p=0.038). Similar results are seen for cases where the driver bypassed the two-truck platoon as in an 8.27% (p=0.074) increase in speed and 28.77% (p=0.103) decrease in distance between the car and trucks. For the four-truck platoon, speed increased by 5.52% (p=0.116) after education. In bypassing cases, the confidence level is smaller; this may be due to smaller sample sizes for bypassing cases.

Table 5-3 compares two-truck platoon scenarios against four-truck platoon scenarios.

Table 5-3. Number of trucks results comparison

			2 Truck		4 Truck	
			Car Speed (mph)	**Distance (ft)**	**Car Speed (mph)**	**Distance (ft)**
No Education	Follow	Mean	39.27	933.71	39.26	943.02
		% Difference			-0.02%	1.00%
		p-value			0.498	0.467
	Bypass	Mean	47.10	-611.45	**56.25**	**-315.69**
		% Difference			**19.42%**	**-48.37%**
		p-value			**0.001**	**0.038**
Education	Follow	Mean	44.33	653.08	42.63	**891.60**
		% Difference			-3.85%	**36.52%**
		p-value			0.142	**0.020**
	Bypass	Mean	51.00	-435.53	**59.35**	**-279.59**
		% Difference			**16.38%**	**-35.80%**
		p-value			**0.001**	**0.032**

There was no significant difference for followers with no education between two- and four-truck scenarios. With education, the average follower distance was 653.08 feet in the two-truck scenario. Four trucks resulted in a 36.52% (p=0.020) increase in the distance participants followed. For scenarios with no education and two-trucks, the average speed and distance of bypassing participants are 47.10 mph and -611.45 feet, respectively. Four trucks resulted in a 19.42% (p=0.001) increase in speed and a 48.37% (p=0.038) decrease in distance. For scenarios with education and two trucks, the average speed and distance of bypassing participants were 51.00 mph and -435.35 feet. Similar to no-education, four trucks resulted in a 16.38% (p=0.001) increase in speed and a 35.80% (p=0.032) decrease in distance.

Table 5-4 shows the number of follows and bypasses sorted against type of signage and level of education.

Table 5-4. Number of follows and bypasses (education and signage)

		No Sign		Truck Platoon		# of Trucks	
		Count	%	Count	%	Count	%
No Education	Follow	43	75.4%	34	57.6%	34	58.6%
	Bypass	14	24.6%	25	42.4%	24	41.4%
Education	Follow	-	-	39	65.0%	40	69.0%
	Bypass	-	-	21	35.0%	18	31.0%

The results show with at least 90% confidence that signage of either type resulted in an increase in the percentage of participants that chose to bypass the truck platoon. There is no significant difference between the two types of signs, as well as between levels of education.

Table 5-5 shows the distribution of follows versus bypasses with respect to the number of platooned trucks.

Table 5-5. Number of follows and bypasses (number of trucks and signage)

		No Sign		Truck Platoon		# of Trucks	
		Count	%	Count	%	Count	%
2 Trucks	Follow	23	82.1%	36	61.0%	36	64.3%
	Bypass	5	17.9%	23	39.0%	20	35.7%
4 Trucks	Follow	20	69.0%	37	61.7%	38	63.3%
	Bypass	9	31.0%	23	38.3%	22	36.7%

Within the two-truck scenarios, the results show with at least 90% confidence that signage resulted in more bypasses. However, within the four-truck scenarios, there was no significant difference between the proportions of follows versus bypasses between “No Sign” and either type of signage. There was also no significant difference between two- and four-truck scenarios within each signage category.

Table 5-6 compares the results of car speed and car-truck distance for the three types of signage and two levels of education.

Table 5-6. Type of signage and level of education results comparison

			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
No Education	Follow	Mean	38.30	1034.42	41.62	901.24	40.88	898.59
	Bypass	Mean	47.43	-670.79	48.36	-556.24	47.75	-497.42
Education	Follow	Mean	-	-	44.77	752.77	43.43	708.10
	Bypass	Mean	-	-	49.38	-462.86	53.00	-456.33
Comparing signs vs. no sign			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
No Education	Follow	% Diff	baseline	baseline	**8.66%**	-12.88%	6.74%	-13.13%
		p-value			**0.035**	0.140	0.081	0.113
	Bypass	% Diff	baseline	baseline	1.96%	-17.08%	0.68%	-25.85%
		p-value			0.407	0.355	0.465	0.269
Education	Follow	% Diff	-	-	-	-	-	-
		p-value	-	-	-	-	-	-
	Bypass	% Diff	-	-	-	-	-	-
		p-value	-	-	-	-	-	-
Comparing "truck platoon" vs. "# of trucks"			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
No Education	Follow	% Diff	-	-	baseline	baseline	-1.77%	-0.29%
		p-value	-	-			0.357	0.491
	Bypass	% Diff	-	-	baseline	baseline	-1.26%	-10.58%
		p-value	-	-			0.416	0.350
Education	Follow	% Diff	-	-	baseline	baseline	-3.00%	-5.93%
		p-value	-	-			0.176	0.312
	Bypass	% Diff	-	-	baseline	baseline	7.33%	-1.41%
		p-value	-	-			0.085	0.463
No Education vs. Education			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
No Education	Follow	% Diff	-	-	baseline	baseline	baseline	baseline
		p-value	-	-				
	Bypass	% Diff	-	-	baseline	baseline	baseline	baseline
		p-value	-	-				
Education	Follow	% Diff	-	-	**7.57%**	-16.47%	6.22%	**-21.20%**
		p-value	-	-	**0.033**	0.085	0.080	**0.033**
	Bypass	% Diff	-	-	2.11%	-16.79%	**10.99%**	-8.26%
		p-value	-	-	0.358	0.267	**0.028**	0.295

Values in Table 5-6 are also measured at the point of the participant car passing the work zone. The mean speed of followers was 38.30 mph with no signage and no education. “Truck Platoon” signage resulted in an 8.66% (p=0.035) increase in speed. Similarly, “# of Trucks” signage resulted in a 6.74% (p=0.081) increase in speed. The mean speed of no-education followers was 41.62 mph with “Truck Platoon” signage and 40.88 mph with “# of Trucks” signage. Education resulted in an 7.57% (p=0.033) and 6.22% (p=0.080) increase these values, respectively. The mean distances of this same group are 901.24 feet with “Truck Platoon” signage and 898.59 feet with “# of Trucks” signage. The following distances decreased by 16.47% (p=0.085) for “Truck Platoon” signage and 21.20% (p=0.033) for “# of Trucks” signage, from education. In the bypassing case, the mean speed was 47.75 mph with “# of Trucks” signage and no education. Education resulted in a 10.99% (p=0.028) increase in this value. There was no significant difference between results for the two signs: “Truck Platoon” and “# of Trucks”.

Table 5-7 compares the results of car speed and car-truck distance with respect to signage and number of trucks.

Table 5-7. Type of signage and number of trucks results comparison

			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
2 Trucks	Follow	Mean	36.87	1037.22	43.42	779.44	42.14	717.83
	Bypass	Mean	51.20	-644.60	47.57	-558.61	49.25	-496.80
4 Trucks	Follow	Mean	39.95	1031.20	43.19	863.24	42.37	869.32
	Bypass	Mean	45.33	-685.33	50.09	-468.61	50.68	-464.36
Comparing signs vs. no sign			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
2 Trucks	Follow	% Diff	baseline	baseline	**17.76%**	-24.85%	**14.29%**	**-30.79%**
		p-value			**0.003**	0.048	**0.010**	**0.017**
	Bypass	% Diff	baseline	baseline	-7.10%	-13.34%	-3.81%	-22.93%
		p-value			0.246	0.401	0.353	0.321
4 Trucks	Follow	% Diff	baseline	baseline	**8.11%**	-16.29%	6.05%	-15.70%
		p-value			**0.028**	0.093	0.090	0.111
	Bypass	% Diff	baseline	baseline	10.49%	-31.62%	11.80%	-32.24%
		p-value			0.168	0.303	0.140	0.300
Comparing "truck platoon" vs. "# of trucks"			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
2 Trucks	Follow	% Diff	-	-	baseline	baseline	-2.94%	-7.90%
		p-value	-	-			0.202	0.288
	Bypass	% Diff	-	-	baseline	baseline	3.54%	-11.06%
		p-value	-	-			0.280	0.353
4 Trucks	Follow	% Diff	-	-	baseline	baseline	-1.90%	0.70%
		p-value	-	-			0.334	0.475
	Bypass	% Diff	-	-	baseline	baseline	1.19%	-0.91%
		p-value	-	-			0.415	0.476
2 Trucks vs. 4 Trucks			No Sign		Truck Platoon		# of Trucks	
			Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)	Car Speed (mph)	Distance (ft)
2 Trucks	Follow	% Diff	baseline	baseline	baseline	baseline	baseline	baseline
		p-value						
	Bypass	% Diff	baseline	baseline	baseline	baseline	baseline	baseline
		p-value						
4 Trucks	Follow	% Diff	8.35%	-0.58%	-0.52%	10.75%	0.54%	21.10%
		p-value	0.083	0.486	0.447	0.214	0.448	0.073
	Bypass	% Diff	-11.46%	6.32%	5.30%	-16.11%	2.91%	-6.53%
		p-value	0.185	0.468	0.192	0.289	0.302	0.336

The mean speed of following cars was 36.87 mph with no sign and two trucks. The “Truck Platoon” sign resulted in an 17.76% (p=0.003) increase in speed and the “# of Trucks” sign resulted in a 14.29% (p=0.010) increase in speed. The mean speed of followers in the four-truck scenario was 39.95 mph, with no sign, and also increased by 8.11% (p=0.028) with the “Truck Platoon” sign and 6.05% (p=0.090) with the “# of Trucks” sign. There was no significant difference between speed results for bypassing cases. The mean distance for followers in the two-truck scenario with no sign was 1037.22 feet. The “Truck Platoon” and “# of Trucks” signage both resulted in a decrease in distance of 24.85% (p=0.048) and 30.79% (p=0.017), respectively. There was no statistically significant difference between the two signs, nor between two- and four-truck results within each signage category.

5.2 Post-Simulator Survey Results

In the post-simulator survey, participants answered questions regarding effectiveness and clarity of education, their understanding of truck platoon signage, and driving behavior when encountering truck platoons. Table 5-8 shows that most participants agreed that education clarifies the meaning of signage and how to react to truck platoons.

Table 5-8. Survey results for education, number of trucks preference, and reaction

Education was…	n	Mean	Median		
…helpful to understand the sign displayed on the truck.	30	4.23	5		
…to clarify how to react with the truck platoon.	32	4.75	5		
Reaction to truck platoons	n	Mean	Median		
more pressure felt when there are more trucks in the platoon	32	3.59	4		
	n	Fewer trucks	More trucks		
preference	32	93.75%	6.25%		
Reaction to truck platoons	n	follow	bypass	merge between	follow others/ don't know
Safest	32	90.63%	9.38%	0.00%	0.00%
Would perform	32	62.50%	34.38%	0.00%	3.13%
From simulator data	293	66.89%	33.11%	0.00%	0.00%

94% of participants believe the safest reaction to truck platoons is to follow. However, when asked what behavior the participant would perform, only 63% claimed they would follow and 34% claimed they would bypass the platoon. Regarding preference to truck platoon size, most participants preferred fewer trucks in the platoon and 56% felt pressure when more trucks are present. Table 5-9 compares the results of questions regarding understanding of signage.

Table 5-9. Survey results for preference towards type of sign

		n	No Sign	Truck Platoon	"# of Trucks"
Identified correct meaning		32	-	100.00%	93.75%
Most preferred		32	6.25%	15.63%	78.13%
Easily understandable	Mean	32	-	3.81	4.06
	Median	32	-	5	5
	Diff	32		0.25	
	p-value	32		0.159	

Given pictures of the two types of signage, most participants were able to correctly identify the meaning of each sign. Seventy-eight percent of participants preferred the “# of Trucks” sign. There was no statistically significant difference between the understandability of either sign. With regards to simulator fidelity, at least 62% of participants felt like they were on a highway and could drive freely.

6 DISCUSSION AND CONCLUSIONS

The simulator-based experiments showed that education on truck platoons and the number of platooned trucks may affect drivers' behavior when interacting with truck platoons while approaching a work zone. The simulator results showed that education reduced the headway between the car and truck platoon from cars that followed or bypassed the platoon. Furthermore, education also resulted in an increase in speed when passing the work zone for drivers that both followed and bypassed the platoon. Car speed results following education were closer to the work zone speed limit of the highway: 50 mph. A reduction in headway and increase in speed could mean that education on truck platoons increases drivers' efficiency when passing a work zone. Operating speeds close to the posted speed limit also mean low speed variance in the work zone. Post-simulator survey results also show that drivers strongly agree that education is helpful in clarifying how to react to a truck platoon. The fact that drivers speed up and reduce their headways after learning about truck platoons could influence how DOTs formulate their education messages. For example, if a DOT wants to counter the increase in speed that could naturally occur after education, then the DOT could be explicit in recommending lower speeds while encountering platoons. Whereas a DOT who wants to promote congestion relief could work on teaching efficient but safe behavior near work zones.

The number of trucks in the platoon may also influence driver behavior when interacting with truck platoons. Simulator results showed that more platooned trucks resulted in an increase in car speed when bypassing the platoon and a decrease in headway after merging in front of the truck. This may be due to the driver having felt the need to speed up when bypassing a truck platoon with a greater number of trucks simultaneously considering the quickly approaching taper. In this case, there may be a concern for safety. Notably, the average speed when passing the work zone in the four-truck bypassing cases are above the speed limit of the road. Ninety percent of drivers indicated in the survey that the safest reaction when encountering a truck platoon is to slow down and follow the platoon. However, only 62 percent of drivers indicated this is how they would react, with some opting to instead bypass the platoon. DOTs could determine that the act of bypassing truck platoons near work zones to be undesirable and implement strategies such as education to counter this behavior.

Drivers may prefer more information about the length of truck platoons when it comes to signage. While there was no statistically significant difference in the simulator data between two types of signs nor a difference in the understandability of the signs from survey data, more participants preferred the "# of Trucks" sign over the other options. On average, participants agreed that more pressure is felt by drivers when there are more platooned trucks. Almost all the participants indicated that they prefer fewer trucks in the platoon.

The simulator results for bypassing cases generally have a wider confidence interval than follower cases. This may be due to the smaller sample size of bypassing cases compared to follower cases. Overall, participants chose to follow the truck platoon in about two-thirds of all scenarios with no significant difference in this ratio with respect to level of education and number of trucks. None of the participants attempted to squeeze between trucks.

In summary, this study investigated the effect of education, truck signage, and the number of trucks in a platoon on driver behavior near work zones. The study confirmed the importance of education and revealed driver tendencies after learning about truck platooning. The study found that signs are effective in changing driver behavior although little difference resulted between the two types of signs that were tested. This research found significant differences in behavior while encountering two versus four trucks in a platoon. In addition to these considerations, there are many other potential issues that could impact the safety and efficiency of work zones when truck platoons are involved. One issue is how to handle truck platoons near ingress and egress points of a highway. A related issue is how best to break up truck platoons while approaching work zones and how early should this be completed in order to reduce negative traffic impacts. Since the form factor and capability of truck signage is still being developed, there is potential for signage to produce other behavior and desirable outcomes that were not investigated in this study. For example, several display manufacturers have produced see-through displays that could enhance trailing driver situational awareness while also providing other information. The proactive investigation of the various factors that affect driver behavior could result in a smoother deployment of the autonomous truck platooning technology.

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APPENDIX A: INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

Institutional Review Board
University of Missouri-Columbia
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November 30, 2020

Principal Investigator: Carlos Chung Sun
Department: Civil/Environmental Engr

Your Annual Update to project entitled INVESTIGATION OF AUTONOMOUS/CONNECTED VEHICLES IN WORK ZONES was reviewed and approved by the MU Institutional Review Board according to the terms and conditions described below:

IRB Project Number	2012126
IRB Review Number	287428
Funding Source	Iowa State University
Initial Application Approval Date	January 07, 2019
Approval Date	November 30, 2020
IRB Expiration Date	January 07, 2022
Level of Review	Administrative
Application Status	Approved
Project Status	Active - Open to Enrollment
Risk Level	Minimal Risk
Type of Consent	Written Consent
HIPAA Category	No HIPAA

The principal investigator (PI) is responsible for all aspects and conduct of this study. The PI must comply with the following conditions of the approval:

1. **COVID-19 Specific Information**
   Enrollment and study related procedures must remain in compliance with the University of Missouri regulations related to interaction with human participants following guidance at research.missouri.edu/about/covid-19-info.php
   In addition, any restarting of in-person research activities must comply with the policies and guiding principles provided at research.missouri.edu/about/research-restart.php, including appropriate approvals for return to work authorization for individuals as well as human subject research projects.
2. No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.
3. All unanticipated problems must be reported to the IRB on the Event Report within 5 business days of becoming aware of the problem. Unanticipated problems are defined as events that are unexpected, related or possibly related to the research, and suggests the research places subjects or others at a greater risk of harm than was previously known or

recognized. If the unanticipated problem was a death, this is reportable to the IRB within 24 hours on the Death Report.

4. On-site deaths that are not unanticipated problems must be reported within 5 days of awareness on the Death Report, unless the study is such that you have no way of knowing a death has occurred, or an individual dies more than 30 days after s/he has stopped or completed all study procedures/interventions and required follow-up.
5. All deviations (non-compliance) must be reported to the IRB on the Event Report within 5 business days of becoming aware of the deviation.
6. All changes must be IRB approved prior to implementation unless they are intended to reduce immediate risk. All changes must be submitted on the Amendment Form.
7. All recruitment materials and methods must be approved by the IRB prior to being used.
8. The project-generated annual report must be submitted to the IRB for review and approval at least 30 days prior to the project expiration date. If the study is complete, the Completion/ Withdrawal Form may be submitted in lieu of the annual report.
9. Securely maintain all research records for a period of seven years from the project completion date or longer depending on the sponsor's record keeping requirements.
10. Utilize the IRB stamped consent documents and other approved research documents located within the document storage section of eCompliance. These documents are highlighted green.

If you are offering subject payments and would like more information about research participant payments, please click here to view the MU Business Policy and Procedure: http://bppm.missouri.edu/chapter2/2_250.html

If you have any questions, please contact the IRB Office at 573-882-3181 or muresearchirb@missouri.edu.

Thank you,
MU Institutional Review Board

APPENDIX B: POST SIMULATOR SURVEY

Participant #: ___ Date ________________________

Investigation of Autonomous/Connected Vehicles in Work Zones

Thank you for sharing your opinions to help us improve safety and efficiency at work zones. A platoon of trucks refers to when trucks follow each other in a caravan. It is important to develop policies that will allows truck platoons and other traffic to travel safely while approaching work zones.

1. Before participating in this study, how familiar were you with Autonomous Truck Platoons?

Not familiar at all [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Very Familiar | [ ] Not sure

Please read the paragraph and answer questions. Please note that this was the material shown earlier during simulator trial.

A "platoon" means that a team of vehicles are travelling together, and they interact with each other within the platoon. A truck platoon means these trucks are moving together as a team. The display on the back of the trucks indicates either trucks are in a platoon, or the number of trucks in this platoon.

2. The paragraph was helpful to understand sign displayed on truck.

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

3. After education, I feel clearer how to react with the truck platoon.

Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

4. Which driver behavior would you perform when encountering truck platoons in/near work zones?
   a) Slow down and follow
   b) Speed up and bypass before entering work zone
   c) Squeeze in and drive between trucks
   d) I will follow what others do

5. Which driver behavior do you think is the safest reaction to truck platoons in/near work zones?
   e) Slow down and follow
   f) Speed up and bypass before entering work zone
   g) Squeeze in and drive between trucks
   h) I do not know

6. I feel more pressure when there are more trucks in the platoon.
Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

7. What is your preference as a vehicle driver encountering the truck platoon?
   [ ] Fewer trucks in the platoon

   [ ] More trucks in the platoon

For the next set of questions, please imagine that you are driving on the road and encounter some trucks and see signs on the back of trucks.

8. What is the meaning of Figure 1?

Figure 1

a) Trucks ask us to follow them
b) Trucks are moving together as a team
c) The sign makes no sense

9. The sign in Figure 1 is easily understandable.
Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

Explain: ____

10. What is the meaning of Figure 2?

Figure 2

a) Trucks ask us to follow them
b) Two/four trucks are moving together as a team
c) The sign makes no sense

11. The signs in Figure 2 is easily understandable.
Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

Explain: ____

12. When encountering truck platoons, which type of signs would you prefer?
[ ] Display "truck platoon" (as Figure 1)

[ ] Display number of trucks in the platoon (as Figure 2)

[ ] No display

[ ] Not sure

13. While driving in the simulator, I felt like I was actually there on the highway.
Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

14. While driving the simulator, I felt like I could drive around freely.
Strongly Disagree [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 Strongly Agree | [ ] Not sure

15. Did any issues arise during the use of the simulator?
    [ ] Yes [ ] No

    If yes, please explain the issue(s) that you experienced:
    ____
    ____
    ____

Please answer the following demographic questions.

16. What is your age range?
    [ ] 18-25 [ ] 26-40 [ ] 41-55 [ ] 56-70 [ ] 71-95

17. What is your gender?
    [ ] Male [ ] Female

18. What is your residency?
    [ ] Urban [ ] Rural

19. What is your regular vehicle type?
    [ ] Passenger Car [ ] Vehicle towing trailer [ ] Delivery/Moving Truck

    [ ] Tractor trailer truck [ ] Bus

20. Please enter any additional comments you may have regarding this study.
    ____
    ____

We are planning on another driving simulator study very soon. If you are interested in it, please leave your email address here:

____

Please feel free to take a flyer and invite your family and friends for the next simulator study.

APPENDIX C: SIMIULATOR SICKNESS QUESTIONAIRE

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

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficult focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. Fullness of the Head	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eye closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

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

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

Source: Kennedy et al. 1993

Please contact Dr. Carlos Sun (csun@missouri.edu) for additional comments, concerns or information on this survey. Thank you for completing this survey! We greatly appreciate your time!

APPENDIX D: RESEARCH PROTOCOL

SOCIAL/BEHAVIORAL/EDUCATIONAL RESEARCH PROTOCOL
UNIVERSITY OF MISSOURI

Project Title: INVESTIGATION OF AUTONOMOUS/CONNECTED VEHICLES IN WORK ZONES
IRB Number: 2012126 MU
Version Number: 2
Version Date: 12/20/18
Principal Investigator: Carlos Sun
Funding Source: Iowa State University (FHWA Pooled-Fund)

I. Research Objectives/Background

1. Describe the purpose, specific aims, or objectives. State the hypothesis to be tested or the research questions that will guide the study.

Autonomous vehicles, and specifically truck platooning, have the potential to result in many benefits such as energy savings via drag reduction, increased capacity via shorter headways, improved safety from faster reaction times, and increased comfort and productivity for drivers. But many unanswered questions surround the deployment of truck platooning near work zones stemming from the interactions with human-driven vehicles. Specifically, what truck platooning policies should be adopted so that traffic can pass through work zones safely? For example, should track platoons be de-coupled far upstream from work zones? If so, how far upstream?

2. Provide the scientific or scholarly background for, rationale for, and significance of the proposed research based on the existing literature and how it will add to existing knowledge.

Specific literature will be discussed and cited under Section XII, References. The literature on truck platooning indicates that truck platooning is expected to be one of the earliest large-scale adoptions of connected and autonomous vehicles (CAVs). The reason for this is because such a deployment involves private commercial fleets that possess adequate financial resources and do not have to involve public commenting and debating over driver autonomy. In the near-term scenario where CAVs have to share the road with human-driven vehicles (HDVs), truck platooning has the potential to impact operations near work zones and/or near entrances and exits on access-controlled highways. Depending on the length of platoons (e.g., three or more), there are different ways in which driver behavior could impact safety and efficiency near work zones. Despite the body of literature examining truck platooning, none has investigated the impact of platooning near work zones.

II. Recruitment Process

1. Describe the recruitment process.

Human participants will be recruited formally via flyers sent to College of Engineering staff and students, and informally via personal invitations using the same flyers or emails. The flyer describes the purpose of the study, provides the study details such as the location and dates, explains the benefits and risks, and presents the compensation provided. The email is a condensed version of the flyer. Both the flyer and the email provide the contact information for the Principal Investigator, Carlos Sun.

2. Describe how and where recruitment will take place.

Recruitment will occur via electronic and face to face invitations in Lafferre Hall and in the City of Columbia.

III. Consent Process

1. Describe the consent process; including who will be asked to consent and what type of consent will be obtained from each subject population, if there is more than one.

After a participant arrives in Lafferre 1510, the orientation process starts with the consent process. The informed consent process will involve study hosts asking participants to read the consent form (SWZDI_ZouTruck Consent Form.docx) and to sign if they agree. A copy of the form will be given the participant.

The consent form will not be emailed beforehand to subjects. Subjects will be given ample time to review the consent form when they arrive for orientation. Subjects will have the opportunity to ask any questions before the simulator orientation process start.

IV. Inclusion/Exclusion Criteria

1. List all inclusion and exclusion criteria.

The study participants will be U.S. drivers and will be College of Engineering students and staff, as well as City of Columbia residents.

2. List any restrictions on participation and appropriate screening procedures to ensure that the restrictions are maintained.

The recruiting flyer will clearly state that this is a driving simulator study and that a participant needs to be a licensed driver in the U.S.

V. Number of Subjects

1. Include the anticipated enrollment number in this study. Include a break-down in numbers if there is more than one subject population.

The anticipated enrollment is 30 participants.

2. Include the statistical analysis or other justification for the number of subjects enrolled.

Due to the detailed information captured in simulator studies, a sample size of 30 is a commonly accepted size. Some simulator studies have used as few as 15 participants.

VI. Study Procedures/Study Design

1. Include a detailed description of the procedures and/or design to be followed (what will subjects be asked to do) and describe each intervention and/or interaction with the subjects and/or their data.

The human subject simulator scenario involves a single lane closure on a four-lane freeway. Such a scenario is one of the basic scenarios that is still able to explore the complexities involved with merging near a work zone taper. A two-truck platoon will approach the work zone. A human subject will drive a sedan and also approach the same work zone at the same time, interacting with the truck. Figure 1 illustrates this scenario where the sedan and the truck platoon both approach the work zone taper at the same time. Different alternatives will be examined in this basic scenario. These alternatives could involve variations on how the following truck de-couples and when it de-couples, DOT policies such as early merge versus zipper merge, traffic level, and the starting lane of the trucks versus the sedan. For comparison, the baseline alternative is the no platoon situation. After the approximately 20-minute long simulator driving, the subject will be asked to complete a post-simulator survey.

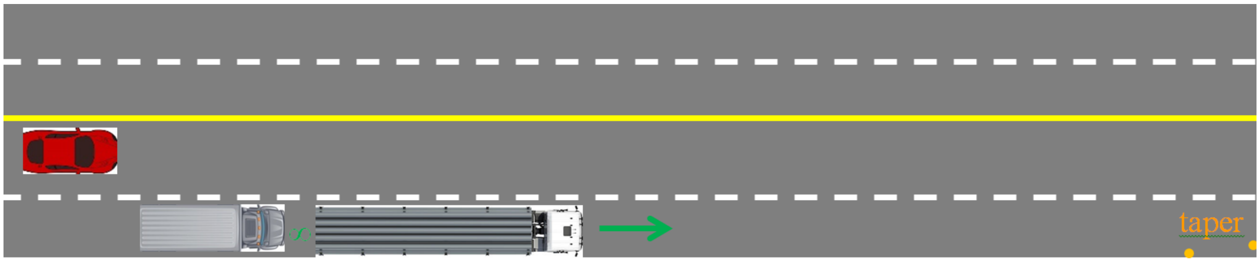


Figure 1. PATP Approaching Work Zone

2. Describe the time commitment involved.

The simulator portion of the study will take approximately 20 minutes with each of the 10 platooning scenarios taking about 2 minutes. Including orientation, simulator warm up, post-simulate survey, and wrap up, the total time commitment approximately 45 minutes. Also, please see the table of events below under point 4.

3. Include whether the procedure/item listed is research-only (occurring only because they are a participant in the research) or routine care/activity (it would occur regardless of the research and you are requesting to collect that data to include in your data analysis).

The procedure is research-only.

4. A table of events may be helpful in this section.

Table 1. Table of study events

Event	**Description**	**~Time (minutes)**
Orientation	Greet participant Obtain informed consent Offer water, restroom break	5
Simulator warm up	Familiarize participant with simulator Free driving	6
Simulator trial	Drive 5 scenarios 2 times each	20
Post survey	Complete post simulator survey	8
Wrap up	Check on participant wellness Offer water again Deliver gift card	5

VII. Potential Risks

1. Describe any reasonably foreseeable risks or discomforts to the subjects and the steps to minimize risks.

Even though the probability of experiencing simulator sickness is low, there is a potential for some participants to experience general discomfort, eye strain, dizziness, and/or nausea. This risk is minimized by keeping the simulator portion short, e.g., 20 minutes or less and ventilating the lab well with double fans. We will also monitor participants closely and inquire about their comfortable between simulator scenarios.

2. Include the plan for reporting unanticipated problems or deviations to the IRB. This plan must include a five-day reporting requirement to the IRB once becoming aware of an event.

At the conclusion of each participant trial, the host will report any problems or deviations to the principal investigator and the team. The team will then devise ways to address or prevent problems and to adjust the study accordingly. Once changes are devised, they will be reported to IRB within the five-day period.

VIII. Anticipated Benefits

1. Describe both direct and indirect benefits for either the individual or society.

The results of the study will benefit the state of Missouri and the nation by analyzing how human-driven vehicles interact with autonomous truck platoons near work zones and recommending policies for truck platooning.

IX. Compensation

1. Describe the amount, method, and timing of disbursement. This includes checks, cash, gifts, extra/course credit, etc.

A $20 gift card to Chipotle, will be delivered to the participant at the conclusion of the simulator session. A participant may drop out at any time during the study without any penalty or loss of benefits.

X. Data Safety Monitoring Plan

Describe the plan to monitor the data, if necessary. A plan is required for treatment and/or intervention studies, sensitive data are being collected, or there is a possibility for subjects to experience adverse events, etc.

1. The plan should include when something needs to be reported
2. The frequency of the monitoring, such as points in time or after a specific number of participants are enrolled
3. Who will conduct the monitoring, such as a data board, medical monitor, investigator, independent physician; the specific data to be monitored
4. Procedures for analysis and interpretation of the data
5. Actions to be taken upon specific events or end points (early stopping rules)
6. Procedures for communication from the data monitor to this site.

1) The data safety monitoring plan exists to ensure that personally identifiable information is kept secure and confidential. There will not be any personally identifiable information stored in the simulator videos, derived data, and surveys. A unique identifier will be assigned and used to link the participant data with the participant. The hash table linking participants with unique identifiers will be locked in a locker inside the locked E1511 laboratory. In case there has been a breach in data security, the event will be reported to IRB and to the affected participants.

2) At the completion of each research day, data will be compiled and locked inside E1511 in Lafferre Hall.

3) The security of data will be monitored by the entire research team, including the principal investigator. The data to be monitored consists of the simulator videos and logs, and the post-simulator surveys.

4) Data will be processed by research assistants. They will review each simulator trial video and log, and derive the necessary measures such as time to platoon, passenger car maneuver (i.e., decelerate, accelerate, change lane), passenger car speeds (i.e., initial, middle, end), and passenger car headways (i.e., initial, middle, end). In addition, they will note any unusual behavior exhibited by the passenger car. Statistical analysis will used to assess passenger car driver behavior differences under different alternatives (i.e., baseline, lights, words, graphics). Data will be stored in an external hard drive in Lafferre E1511 in a locker along with the paper surveys.

5) The host shall monitor participants carefully and interrupt the study whenever there is evidence of participant discomfort. Whenever a host discovers that a participant experiences discomfort, the host shall immediately offer to stop the study (early stop) and remind the participant that there will be no loss of compensation. The host shall also offer bottled water to the participant, and offer a place for the participant to sit and rest.

6) The data monitor, Dr. Sun, will email or telephone IRB (irb@missouri.edu) directly with information on problems.

XI. Multiple Sites

1. Specify who is the lead site and describe the roles of each site in the study.

There is only one study site: Lafferre Hall, E1510 (ZouSim Laboratory), at the University of Missouri (MU).

2. Indicate whether all required approvals are already in place or will be in place at each site prior to project implementation. If the study will utilize a reliance agreement or a single IRB, please describe which institution(s) will be relying on another IRB for review, and which institution will be responsible for the IRB oversight of the relying IRB(s).

Only IRB at MU will be involved.

3. Describe the plan that is in place to manage information obtained from multiple sites that may be relevant to the protection of human subjects such as reporting unanticipated problems, protocol modifications, and interim results.

Not applicable.

XII. References

1. Findings from a literature search or pilot study must be outlined including appropriate detailed references to earlier studies and data.

2. If necessary, additional references to supporting data or additional information may be included in an appendix.

Research and testing on various truck platooning topics have skyrocketed over the past few years. Muratori et al. (2017) discussed the potential benefits of improved fuel efficiency and increased highway capacity and Zhou et al. (2018) analyzed capacity characteristics of platooning on four-lane freeways. Many researchers, such as Qin and Wang (2018), focus on the analysis of platoon control; Duret et al. (2018) focused specifically on platoon splitting for merging. Some investigated planning for truck platooning (Bhoopalam et al. 2018). Many analyzed laws and regulations (Wagner et al. 2017) and the specific issue of truck only lanes (Mahamed et al. 2018). A trucking simulator has been a useful tool used for investigating driver behavior under truck platooning (Hjalmdahl et al. 2017). Despite the plethora of recent research on truck platooning, no one has yet examined the impacts of truck platooning near work zones and, specifically, the issues that arise near a typical lane closure scenario.

Partially Automated Truck Platooning (PATP) refers to a truck platooning system where the speed and spacing are automatically controlled, but a driver maintains full control over steering and can take over acceleration and braking at any time (FHWA 2013). PATP is SAE level 1 automation, meaning a vehicle assists the driver with some parts of the driving task, but the human operator is still primarily responsible (NHTSA 2016). The PATP scenario is chosen for this investigation because it is the near-term implementation of truck platooning that is currently undergoing field trials. Therefore, DOTs could see such truck platoon operating on roadways, possibly within a year.

Bhoopalam, A., Agatz, N., and Zuidwijk, R. (2018). Planning of Truck Platoons: A Literature Review and Directions for Future Research. Transportation Research Part B: Methodological, Vol. 107, Elsevier.

Duret, A., Wang, M., and Leclercq, L. (2018). Truck Platooning Strategy Near Merge: Heuristic-Based Solution and Optimality Conditions. Transportation Research Board 97th Annual Meeting, Washington, D.C. Jan. 7-11.

FHWA (2013). Partially-Automated Truck Platooning Demo. Federal Highway Administration.

Hjalmdahl, M., Krupenia, S., and Thorslund, B. (2017). Driver Behaviour and Driver Experience of Partial and Fully Automated Truck Platooning – A Simulator Study. European Transport Research Review, Vol. 9, Iss. 1. Springer.

Mohaned, A., Laman, H. Oloufa, A., and Abou-Senna, H. (2018). A Framework for Assessing the Impacts of State Level Platooning Truck Only Lane Strategies in Florida. Transportation Research Board 97th Annual Meeting, Washington, D.C. Jan. 7-11.

Muratori, M., Holden, J., Lammert, M., Duran, A., Young, S., and Gonder, J. (2017). Potentials for Platooning in U.S. Highway Freight Transport. WCX 17: SAE World Congress. Detroit, April 4-6.

NHTSA (2016). Federal Automated Vehicles Policy. National Highway Traffic Safety Administration.

Qin, Y. and Wang, H. (2018). Stability Analysis of Connected Vehicular Platoon with Multiple Delayed Feedbacks. Transportation Research Board 97th Annual Meeting, Washington, DC. Jan. 7-11.

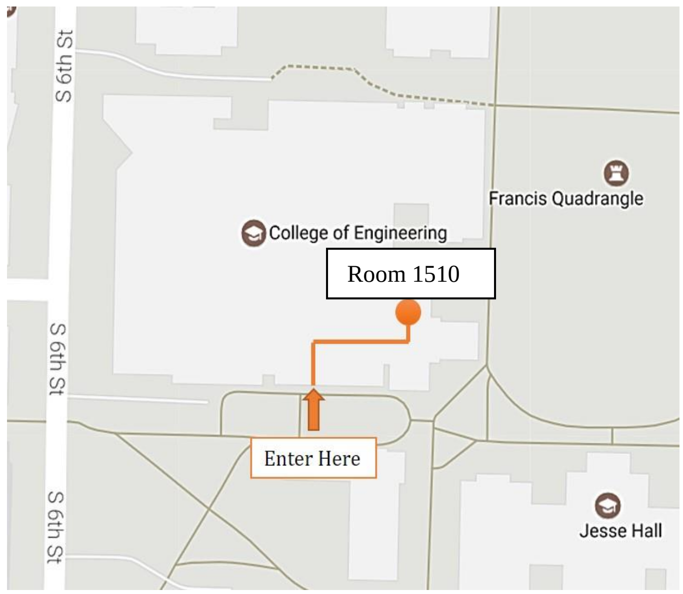
Wagner, J., Lukuc, M., and Moran, M. (2017). Regulatory and Legal Review of Automated and Connected Truck Platooning Technology. Transportation Research Board 96th Annual Meeting, Washington, D.C. Jan. 8-12.

APPENDIX E: RECRUITMENT FLYER

INVESTIGATION OF AUTONOMOUS/CONNECTED VEHICLES
IN WORK ZONES

What: You are warmly invited to participate in a driving simulator research study at the University of Missouri to help enhance traffic safety. Participants will drive on a simulated freeway and give their opinions on autonomous truck platooning near work zones. The study will take approximately 45 mins.

Where: The study will take place in the ZouSim Lab in E1510 Lafferre Hall
- Enter through the south door into Overholser Atrium.
- Turn right down the hallway to the small staircase
- Go up staircase and the room will be on the left side.
- Street metered parking available near Lafferre Hall



When: April/May, 2019

Benefits: Your feedback will help to improve traffic safety in Missouri.

Risks: A small percentage of participants may experience some simulator discomfort such as eye strain or dizziness.

Compensation: A participant may withdraw from participation at any time for any reason without losing the $20 gift certificate to Chipotle.

Confidentiality: Personal identifying information will be kept confidential.

Thank you for your help in improving traffic safety in Missouri. Participants must be 18 years of age and a licensed U.S. driver.

If you are interested in participating in this study, please contact Dr. Carlos Sun in the Department of Civil and Environmental Engineering at csun@missouri.edu or 573-884-6330.

APPENDIX F: HUMAN SUBJECT CONSENT FORM

INVESTIGATION OF AUTONOMOUS/CONNECTED VEHICLES IN WORK ZONES

PARTICIPANT CONSENT FORM

You are being asked to take part in a research study involving connected vehicle (CV) truck platoons and vehicle interactions. A truck platoon is 2 or more trucks traveling with short headways using automated driving technologies. We are asking you to take part in this study to obtain your feedback about driving near truck platoons. Please read this form carefully and ask any questions you may have before agreeing to take part in the study. Participants must be 18 years of age and a licensed driver in the U.S. The number of participants in the study is 30.

What the study is about: The purpose of this study is to learn about truck platooning near work zones.
What we will ask you to do: If you agree to be in this study, we will ask you to drive a car simulator through a sample road freeway network. We will collect data from the simulator trip to help us evaluate how to best formulate truck platooning policy. Upon completion of the simulator trip, we will ask you to take a brief survey of four pages. The survey will ask you about your preferences interaction with trucks near work zones. The entire study, including orientation, will take approximately 45 minutes.
Risks and benefits: Even though the probability of experiencing simulator sickness is low, there is a potential for some participants to experience general discomfort, eye strain, dizziness, and/or nausea. The results of the study will benefit the state of Missouri learning about truck platooning near work zones.
Compensation: A $20 gift card to Chipotle, will be offered. A participant may refuse to participate at any time during the study without any penalty or loss of benefits.
Your answers will be confidential. In any type of report that we make public, we will not include any information that will make it possible to identify you individually. Research records will be kept in a locked file; only the researchers will have access to the records.
Taking part is voluntary: Taking part in this study is completely voluntary. You may skip any survey questions that you do not want to answer. If you decide to take part in this study, you are free to withdraw at any time without the loss of compensation.
If you have questions: The researcher conducting this study is Dr. Carlos Sun. Please ask any questions you have now. If you have questions later, you may contact Dr. Sun at csun@missouri.edu or 573-884-6330. If you want to talk privately about your rights or any issues related to your participation in this study, you can contact University of Missouri Research Participant Advocacy by calling 888-280-5002 (a free call) or emailing muresearchrpa@missouri.edu. If you have any questions or concerns regarding your rights as a participant in this study, you may contact the Institutional Review Board (IRB) at 573-882-3181. You will be given a copy of this form to keep for your records. The information we collect from you for this study will not be used or shared with other investigators for future research studies.

Statement of Consent: I have read the above information and have received answers to any questions I asked. I voluntarily consent to take part in the study.

Your Signature ___________________________________ Date ________________________

Your Name (printed) ____