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DRIVER PERFORMANCE DUE TO UNMANNED AERIAL SYSTEM APPLICATIONS IN THE VICINITY OF SURFACE TRANSPORTATION

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APPLICATIONS IN THE VICINITY OF SURFACE TRANSPORTATION

A Project Presented

by

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MAY 2019

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ABSTRACT

DRIVER PERFORMANCE DUE TO UNMANNED AERIAL SYSTEM APPLICATIONS IN THE VICINITY OF SURFACE TRANSPORTATION

MAY 2019

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Unmanned aerial systems (UAS), or drones, have become increasingly utilized for a myriad of applications in the vicinity of the roadway and can offer a low-cost alternative to many labor-intensive data collection techniques, including infrastructure inspection, roadway marking data collection, and more. To collect much of this data with a desired degree of accuracy, UAS must be flown near moving vehicles, pedestrians, and/or bicyclists. However, UAS, and their pilot/crew, have the potential to be a distraction to drivers. A study by Hurwitz et al. suggests that UAS operations are more distracting to drivers as the UAS traverses closer to the roadway laterally. Through a combined literature review and full-immersion driver simulator study, this study furthered the current state-of-the-literature and investigated the potential for UAS to be flown near roadways in the future as well as potential safety implications of those circumstances. Specifically, driver performance due to drone height and the presence of drone operators was evaluated. The literature synthesis portion of this research revealed that UAS flights in the vicinity of roadways will continue to increase. The results of the driving simulation study showed that participants were more visually distracted in situations where the pilot and drone were both present compared to the drone only. Further, in 11% of all analyzed situations, participants

were critically visually distracted (continuous glance of two seconds or more) by the drone or pilots. Ultimately, this research provides recommendations to policymakers for creating regulations on the use of drones in the vicinity of roadways.

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CHAPTER 1: INTRODUCTION

In 2016 alone, over 39,000 lives were lost in the transportation system, with a majority occurring on roadways and highways (*3*). Addressing human behaviors can decrease this safety risk, as approximately 94 percent of crashes are due to human error (*4*). Further, nine percent of fatal crashes in 2016 were reported as distraction-affected crashes, demonstrating that distracted driving is a main contributor to reduced roadway safety (*5*). At the same time, Unmanned Aerial Systems (UAS), or drones, have been increasingly utilized throughout the globe in the transportation industry in recent years to decrease cost and increase safety (*6*). This new lightweight, low-cost technology is portable and applicable for many different tasks, including bridge inspections, 3D mapping, and crash reconstruction (*6*). From the sky, these devices are able to collect detailed information and capture aerial images with little amounts of effort and time. In recent years, UAS have begun to be appreciated for applications in traffic monitoring (*6–11*). Their ability to capture video above a roadway can be combined with object-tracking techniques to track vehicles, extracting vehicle data such as speed, counts, and trajectory data (*12–14*). This data collection method can be useful for traffic engineering studies and can save time in the field, as UAS are able to collect large amounts of data in shorter amounts of time. In Massachusetts, the speed limit–setting process requires many locations to be studied, with data collected at each (*15*). The Massachusetts Department of Transportation (MassDOT) acknowledges that, ideally, observations would be taken continuously throughout a proposed speed zone. However, in their most recent edition of "Procedures for Speed Zoning on State and Municipal Roadways" in 2017, MassDOT asserts that continuous data is not practical to collect (*15*). With UAS technology, continuous speed data collection

becomes possible, allowing a potential opportunity for a more efficient speed limit creation process, which would, in turn, increase safety.

Speed is a substantial contributor to crashes in the United States. From 2005 to 2014, speeding was a factor in over 112,000 fatalities, representing thirty-one percent of all traffic fatalities during that period (*16*). As speed limits promote roadway safety, they must be set reasonably and appropriately, reflecting the roadway environment and driver expectations. If operating speed data is more detailed and able to be collected continuously along a study area, then it is better understood. This expectantly results in speed limits that are more effective. Thus, using UAS for speed data collection in the speed limit–setting process has the potential to improve safety and increase efficiency for the public agencies responsible for the process.

On the other hand, UAS have the potential to distract drivers if flown in the vicinity of a roadway to collect this data. External, or out of vehicle, distractions were identified as contributing factors of 29 percent of all crashes that were reported between the years of 1995 to 1999 (*17*, *18*) and can often take the form of visual distractions. Visual distractions have the potential to increase crash risk greatly, as eye glances away from the forward roadway two seconds or greater in length double the risk of a crash or near crash (*19*). For UAS specifically, a study by Hurwitz et al. suggests that UAS operations are distracting to drivers, with the level of distraction increasing as UAS traverse closer to the roadway laterally (*2*).

1.1   Motivation

The connection between UAS and safety motivating this research is outlined in Figure 1.
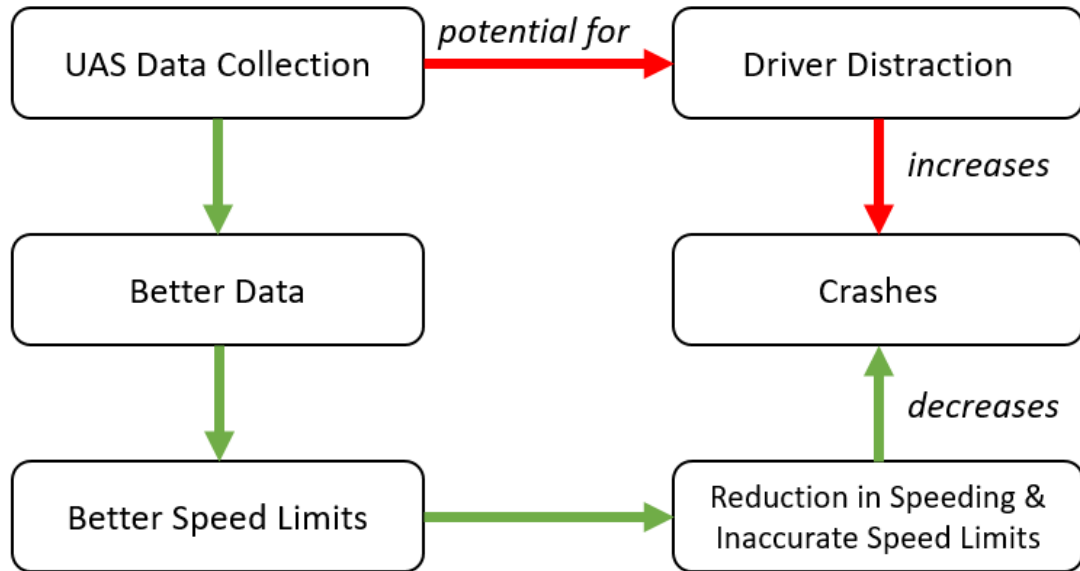
Figure 1: Speed data collection via UAS and safety relationship

As shown, UAS are able to offer efficient data collection, which can lead to creating safer roadways and speed limits. Additionally, UAS have the potential to be a distraction to drivers, causing crashes. This figure is just one example of the benefit-cost of such data collection using UAS, outlining why it is important that UAS for data collection purposes and distraction be understood. Currently, there exists a gap in literature on how UAS in the vicinity of roadways affect driver performance in varying circumstances. Given this, policies and standards are not able to reflect the safe and unsafe ways in which UAS are utilized in the vicinity of roadways. To create a safe roadway environment while maintaining the innovative and beneficial uses of UAS in the United States, it is crucial that driver performance in response to UAS at varying heights and operator presence be understood, which would be necessary in any circumstance when collecting data using UAS.

1.2 Research Objectives

As identified in the problem statement, the main goal of this research was to study driver performance in environments where UAS and their remote pilot and observers are present in the vicinity of roadways. Specifically, this research aimed to answer research questions related to driver performance and response outlined in the following sections.

1.2.1 Use in Transportation

Understanding the current and future uses of UAS for transportation-related tasks or general use in the vicinity of roadways is vital to determine how they will be flown near drivers. The following preliminary questions outlined below are aimed to be answered through this research.

- What is the feasibility of using UAS for transportation-related purposes in the vicinity of roadways?

- How are UAS currently being used in the vicinity of roadways and how will they be used in the future?

1.2.2 Visual Attention, Speed, and Lateral Position

Understanding a driver's visual attention, speed, and change in lateral position is crucial to determine their level of distraction due to UAS or operator presence. Additionally, understanding if familiarity of UAS influences their performance is vital to determine if education of UAS is important for UAS to be more or less visually distracting to drivers. This research aims to answer the following research questions.

How is a driver's visual attention, speed, and lateral positioning influenced by:

- The altitude of the UAS immediately adjacent to the roadway?

- Operator presence on the roadside?

- Their familiarity of UAS?

1.3   Scope

While there exist many potential factors that may influence driver performance due to flying UAS and operator presence, the scope of this study focused solely upon UAS height above and immediately adjacent to the roadway and operator presence, based on the literature review findings. It is also recognized that many variables effect driver speed, lateral position, and eye glance behavior. Thus, other variables, such as traffic volumes, road condition, weather conditions, roadway path, and functional classification were held constant or not considered as variables in this study.

CHAPTER 2: BACKGROUND

Concepts relating to the safety advantages and disadvantages of UAS are discussed in the following section, including the need to collect speed data and to limit external distractions to increase safety, UAS applications in transportation and other industries, current UAS regulations, and simulator study effectiveness. Published literature was evaluated and compiled on these topics to identify previous work. These works are presented in the following sections.

2.4   Safety Impacts of Speed Limits

Speed limits are often a point of interest and controversy in a community. The Federal Highway Administration (FHWA) conveyed this through their report "Methods and Practices for Setting Speed Limits: An Information Report" by stating, "Selecting an appropriate speed limit for a facility can be a polarizing issue for a community. Residents and vulnerable road users generally seek lower speeds to promote quality of life for the community and increased security for pedestrians and cyclists; motorists seek higher speeds that minimize travel time. Despite the controversy surrounding maximum speed limits, it is clear that the overall goal of setting the speed limit is almost always to increase safety within the context of retaining reasonable mobility" (*20*). In MassDOT's own guide of procedures for speed zoning, this statement is referred to, reinforcing that speed limit setting is no easy task. This is why Massachusetts DOT only establishes posted speed limits after an engineering study has been conducted (*15*).

As FHWA described, the overall goal of setting the speed limit is almost always to increase safety while retaining reasonable mobility (*20*). As many crashes are due to

speeding, as described in this section, speed limit setting must be done with care to ultimately create the safest roadway environment.

2.4.1 Crashes due to Speeding

The National Highway Traffic Safety Administration considers a crash to be "speeding-related" if a driver was "charged with a speeding-related offense or if an officer indicated that racing, driving too fast for conditions, or exceeding the posted speed limit was a contributing factor in the crash" (*21*). Of the over 9,000 speeding-related fatalities in 2014, approximately 6,000 (64%) were the drivers of speeding vehicles; 2,000 (20%) were passengers in speeding vehicles; 1,000 (12%) were occupants in other vehicles; 300 (3%) were pedestrians; and 50 (0.5%) were bicyclists (*16*). In the United States, speeding is a clear issue. However, speed limits cannot simply be changed to motivate drivers to operate at slower speeds. Speed limits must be set appropriately, as simply lowering a posted speed limit, without additional enforcement, educational programs, or other engineering measures, has little effect on the speed at which drivers will operate (*22*). Regarding increase in speed limits, a recent study by Monsere et al. found that speeds increased and number of crashes increased on highways where posted speed limits were increased (*23*). In general, if the engineers and agencies that set speed limits want drivers to respect speed limits, the speed limits must reflect the reality of the driving conditions. This cannot be done solely through enforcement, which will foster resentment instead of respect. Following proper speed limit setting procedures and collecting accurate data can allow for appropriate speed limits to be set, creating a safer roadway environment.

2.5   Speed Limit Setting

Traditionally, speed limits on newly constructed roadways are established from the design speed of the roadway segment. Generally, many speed limits have remained unchanged since they were founded during original construction and are no longer appropriate for the conditions. Speed limit modification studies are induced in different ways, including through town or city officials receiving complaints from the public or through an investigation of crash history.

2.5.1   Speed Limit Selection Process

The speed limit selection process for roadways in the United States is, and always has been, the responsibility of state and local governments (*20*). The National Cooperative Highway Research Program Report 500, which provides guidance on the American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan, states that a speed limit should depend on four factors: design speed, vehicle operating speed, safety experience, and enforcement experience (*24*). Design speed is based on a major portion of the roadway, not necessarily its most critical design feature, such as a sharp curve (*24*). As many design factors, such as adjacent land use and road type for example, are based on anticipated use; a design speed does not always match the actual operating speed of a roadway (*16*). Vehicle operating speed is considered from a range of 85th percentile speeds taken from a spot-speed survey of free-flowing vehicles at specific points on a roadway. This speed is widely recognized as the most utilized analytical method for selecting the posted speed limit as it includes many drivers' speeds, or, rather, 85 percent of vehicles on a roadway are not exceeding that speed (*16*, *24*). However, the National Transportation Safety Board concluded in its 2017 Safety Study that "the

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MUTCD (Manual on Uniform Traffic Control Devices) guidance for setting speed limits in speed zones is based on the 85th percentile speed, but there is not strong evidence that, within a given traffic flow, the 85th percentile speed equates to the speed with the lowest crash involvement rate on all road types" (*16*). Additionally, a 2016 Insurance Institute for Highway Safety report stated that the 85th percentile speed was not a stationary point, but, rather, a moving target that increases when speed limits are increased (*25*).

Safety experience, or crash frequencies and outcomes, are also considered in the AASHTO guidance of the speed setting process (*24*). To consider factors other than operating speed, such as crash history, in an effective manner, FHWA developed an expert web-based system, known as USLIMITS2. This tool is designed to help practitioners set "reasonable, safe, and consistent speed limits for specific segments of roads" (*26*). The input variables into the system include road function, crash history, pedestrian activity, and existing vehicle operating speeds. For engineers, the system can provide an objective second opinion (*26*). Enforcement experience is the final factor that is considered by AASHTO in the speed limit setting process (*24*).

Within the Commonwealth of Massachusetts, the process for establishing new speed limits depends upon roadway ownership (*15*). MassDOT procedures declare that in each case of exploring a new speed limit, an engineering study must be completed, which includes speed data collection based on free-flow traffic. The locations in which this speed data must be collected is dependent upon locality and uniformity of physical and traffic conditions but is typically spaced at intervals equal to or less than 0.25 miles (*15*). With a potential of long roadway sections of even just five miles or longer, the minimum number of study locations can be large. Currently, it is in general practice to collect speeds using a

RADAR or LiDAR gun on the side of a roadway outside of plain view during weekday, off-peak hours under ideal weather conditions (*15*). These devices can only collect speed at a singular point along a roadway. MassDOT acknowledges that, ideally, these observations would be taken continuously throughout a proposed speed zone. However, in their most recent edition of "Procedures for Speed Zoning on State and Municipal Roadways" in 2017, MassDOT asserts that continuous data is not practical to collect (*15*). At each study location, a minimum of 100 or more speed observations must be recorded in each direction; on low volume roadways, observations may end after two hours if that value is not reached (*15*). Depending on the number of study locations, this can be a time-consuming and expensive process. LiDAR guns themselves cost $2,000 to $3,000, on top of the person-hour labor costs (*27*). For each study collection in the field, a "Sheet Distribution Worksheet" is filled out with the following information: 95th percentile speed; 85th percentile speed; 50th percentile speed; mode; and pace (*15*). After speed data collection, a "Speed Control Summary Sheet" is prepared at each study location, which requires all existing geometric conditions and constraints to be noted and mapped, including vertical curves, grade (if known), traffic volumes, side streets and major driveways, and adjacent land uses (*15*). Finally, among other factors in the speed setting process, the collected speeds are analyzed to create a safer speed limit for a given length of roadway (*15*). After a new speed limit is set, it is recommended in MassDOT procedures that a follow-up study be completed, requiring more time in the field and additional costs (*15*).

2.5.2   Point Speed Capture Limitations in the Speed Setting Process

Traditionally, speed data collection methods have utilized point speed capture, with continuous speed data considered impractical to collect (*15*). Point speed capture devices, such as RADAR, LiDAR, pneumatic tubes, and inductive loops, can each only collect speed data at a specific point along a roadway. As described above, the speed limit setting process requires the existing operating speed along a study section of roadway to be fully analyzed at multiple points along the roadway. Utilizing only point speed capture devices, this can be an expensive and time-consuming process over a stretch of roadway. Continuous speed data, if it is able to be collected along a roadway segment, would provide benefits such as inexpensive collection and short turnaround time. Additionally, continuous data collection could provide new opportunities in the speed limit setting process, such as determining specific locations where the speed limit should change. Today, smartphone apps and GPS devices are able to capture this data; however, a shortcoming of this type of data collection is that it is not entirely limited to free-flow speeds, as there is a lack of information related to the time headway between vehicles (*27*, *28*).

As point speed capture data collection devices only allow for speed data to be collected at a single point along a roadway, only time-mean speed can be collected. According to the FHWA Travel Time Data Collection Handbook, time-mean speed is the "arithmetic average speed of all vehicles for a specified period of time" (Equation 1-1) (*29*). This differs from space-mean speed, which is defined as the "average speed of vehicles traveling a given segment of roadway during a specified period of time and is calculated using the average travel time and length for the roadway segment" (Equation 1-2) (*29*). In general, time-mean speed is associated with a point over time and space-mean

speed is associated with a section of roadway. From the FHWA Handbook, all authors agree that space-mean speed, rather than time-mean speed, is necessary to compute a theoretically correct speed (*29, 30*).

$$\text{Time-Mean Speed: } \overline{v_{TMS}} = \frac{\sum v_i}{n} = \frac{\sum \frac{d}{t_i}}{n} \qquad (1\text{-}1)$$

$$\text{Space-Mean Speed: } \overline{v_{SMS}} = \frac{d}{\frac{\sum t_i}{n}} = \frac{n \times d}{\sum t_i} \qquad (1\text{-}2)$$

where: d = distance traveled or length of roadway segment
          n = number of observations
          v_i = speed of the *i*th vehicle
          t_i = travel time of the *i*th vehicle

2.5.3 Traditional Speed Collection Techniques

There are three categories of portable speed detector devices: intrusive, nonintrusive, and off-roadway (*31*). Appendix A: Traditional Count Devices outlines examples of each of these types of technology, providing advantages and disadvantages. Each type of technology described in Appendix A: Traditional Count Devices are all point speed capture devices.

2.6 Safety Implications of Distractions

Distracted driving within transportation is a vital safety issue and has been the focus of many research efforts. In 2016 alone, there were 3,450 fatalities that were distraction affected crashes, 9.2 percent of the total driver-related fatalities that year (*32*). In 2015, there were approximately 391,000 injured due to a motor vehicle crash involving distracted drivers (*33*). Distracted driving can be defined as "any activity that diverts attention from driving" (*34*). While many different forms of distraction can exist in a driving environment, there are three types of distractions: visual, manual, and cognitive. Many research studies

completed to date have focused on internal vehicle distractions, such as cell phone use. A driving study completed by Kristie et al. evaluated drivers in a naturalistic environment and provided participants with two tasks, one visual distraction and another verbal (*35*). Of the 23 drivers who completed this driving task, it was found that drivers made a total 268 errors when distracted and 182 errors when driving undistracted. Individually, it was found that drivers completed 11.7 errors, on average, when distracted compared to 7.9 when not distracted. These errors included exceeding the speed limit, lane deviation, and accelerating too fast (*35*). Further, a study completed by Wenners et al. concluded that cell phone use particularly, which includes each type of distraction (visual, manual, and cognitive), is a significant issue. This observational study that took place in Massachusetts in 2012 concluded that the average daytime cell phone use is 7.0 percent (*36*). With these studies, and others, it is widely recognized that internal, or in-vehicle, distractions are a significant problem (*17*, *18*, *37*, *38*).

2.6.1   External Distractions

In recent years, as discussed in the previous section, much research has concentrated on internal (or in-vehicle) distractions rather than external (or out-of-vehicle) distractions. External distractions were identified as contributing factors of 29 percent of all crashes that were reported between the years of 1995 to 1999 (*17*, *18*). External distractions can often take the form of visual distractions. As mentioned previously, eye glances away from the forward roadway lasting two seconds or greater in length double the risk of a crash or near crash (*19*). Given this significant increase of crash risk, external visual distractions are a critical safety issue. While there have been several attempts to evaluate the effects of various types of external distractions, including video billboards, digital billboards, and

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wind farms on driver behavior and vehicle control, these types of distractions remain under-evaluated (*39–41*). From the few completed studies on the topic, it can be concluded that external distractions have effects on the eye movement of drivers and vehicle control performance of drivers. A study by Chan et al. found that experienced drivers and novice drivers have similar eye movement behaviors in external districted environments (*40*). This differs from studies of internal distraction, where novice drivers often are more distracted than experienced drivers (*42*). Specific studies evaluating external distraction are further discussed in this section.

A driver simulator study completed by the Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE) evaluated driver performance, including lane and speed variability, due to roadside distractors (*43*). A total of 46 participants completed at least one session in this data collection, and of these participants, ten were found to have attention deficit tendencies. Drivers with attention deficit disorders have increased rates of driving incidents and infractions; thus, this research aimed to investigate the effects of roadside distractors on performance of drivers with and without attention deficit tendencies. The report from this study concluded that drivers had more lane position and speed variability in the presence of roadside distractors compared to segments of roadway without any distractors. However, the only statistically significant differences in lane position or speed were those scenarios of work zone and billboard distractors. Further, it was found that drivers with attention deficit tendencies had significant increases in variability for lane deviations relative to the control group (*43*).

Video billboard signs have been found to receive significantly more long glances (greater than 0.75 seconds) than passive billboard signs (*39*). A driving simulator study by

Milloy and Caird found that in the scenario of a lead vehicle braking, roadway segments with the presence of wind turbines did not correspond to significant differences in driver braking compared to baseline segments (*41*). However, drivers adopted slower speeds in the presence of wind farms than without their presence. In a similar study with video billboards scenarios, significantly more rear-end collisions occurred in response to the hard lead-vehicle braking event compared to control conditions (*41*).

A study completed by Divekar et al. evaluated external distractions on drivers in a simulated environment (*44*). In this study, participants were asked to navigate a virtual world while understanding secondary search tasks outside of the vehicle at various points. This task was similar to scanning a sign on the side of a roadway for some information relevant to a particular trip. A total of 48 drivers participated in the study, with 24 novice drivers (between the ages of 16 and 18 years old) and 24 experience drivers (21 years of age or older and at least five years of driving experience). This study concluded that external tasks are distracting not only for novice drivers, but also for more experienced drivers. This study also provided evidence that peripheral vision is not adequate to perform the task of hazard anticipation when attention is focused elsewhere besides the forward roadway (*44*).

2.6.2 External Distractions due to UAS

To date in published literature, distraction due to UAS has only been studied by Hurwitz et al. (*2*). This study evaluated drone operations near roadways using a driving simulator. The effects on driver distraction due three independent variables of the drone were analyzed: lateral offset, flight path, and land use. A total of 39 participants completed the study (17 women and 24 men). All scenarios included two drone operators and one drone.

It was found that total fixation and eye glance duration on the drone increased the closer the operation was to the roadway laterally. Additionally, drone operations were seemly more distracting in rural environments. Finally, this study revealed that drones created potential unsafe glances over two second in length at the greatest frequency when they were zero feet away laterally from roadway.

2.7   Unmanned Aerial System Applications

UAS have historically been used for military applications. However, with the commercialization and reduction in cost and size of UAVs in recent years, the potential uses for these devices has grown. UAS are comprised of three components: (1) the aircraft, or UAV; (2) communication and control; and (3) the pilot on the ground. The terms UAS, drones, unmanned aerial vehicles, UAVs, and unmanned aerial systems are often used interchangeably. UAS applications have been explored for many uses, including for traffic monitoring, structural inspection, topographic surveying and mapping, and crash reconstruction (*45*). In a survey report by AASHTO in 2016, four specific benefits of UAS use were highlighted: improved safety, time savings, decreased cost, and even decreased congestion, as there would no longer be a need to shut down lanes for stationary vehicles and machinery to complete tasks such as bridge inspections (*6*).

2.7.1   Traffic Monitoring

In recent years, UASs have been introduced to the transportation community as a cost-effective solution to collect trajectory data from the sky and replace the old approach of using pre-installed static cameras. Table 1 below presents a comparison of static camera use and UAS use for traffic monitoring and other related applications based on research.

Table 1: Comparison between a static camera and an unmanned aerial system

Metric	Static Camera	UAV
Security/Privacy	Medium	Low
Cost (acquiring and maintenance)	Low	Low
Reusability	Low	High
Energy efficient	Low	High
Deployment difficultly	Low	Low
Operational time	High	Low
Operation under adverse weather	Medium	Low
Safety risks	Low	Medium
Endurance	High	Low
Video post-processing skills required	Medium	High
Data transfer, communication and storage	Low	High
Operation skills required	Low	Medium
Training requirement	Low	Medium
Complexity	Medium	Medium

(adapted from Barmpounakis et al. (10))

Most UAVs have the flexibility to collect large amounts of aerial data almost anywhere in a matter of minutes. Additionally, UAVs can be programmed to automatically fly a particular route to collect specific aerial imagery, creating simplicity in the flying process for the pilot. Their small size also is beneficial to collect naturalistic data over a roadway, allowing for a more nonintrusive recording of traffic data. However, a noteworthy limitation of UAVs are their small battery capacities, which only allow them to fly for short periods of time, often for only 20 to 30 minutes (*8, 11*). However, provided that UAVs can fly above a highway and collect the speeds of many vehicles at once, it is possible to collect more traffic data during that short amount of time than traditional

methods. MassDOT procedures require that 100 vehicle speeds be collected during a weekday at off-peak hours at a singular location on a roadway for the speed limit–setting process, as mentioned previously (*15*). Depending on the off-peak volume of the roadway of interest, this may not take much time to collect by UAV.

For example, on Thursday, November 17, 2016, count data was collected by MassDOT in Athol, Massachusetts, on the Mohawk Trail, a portion of Route 202 (*46*). From the period between 11 a.m. and 3 p.m., the average traffic volume was approximately 750 vehicles per hour. Assuming an ideal case of all vehicles traveling at free-flow speed, a UAS would only need to actively collect data in the sky for approximately eight minutes for 100 vehicle speeds to be collected. Even in a less than ideal case including fewer free-flow vehicles and assuming that only fifty percent of vehicles would be traveling at free-flow speed, the UAS would only need to collect data for 16 minutes. Thus, it is possible that for many roadway situations, the short battery life may not cause any issues. Extra batteries may also be carried if more than one deployment is necessary. Another issue may be that, according to FAA regulations Part 107, UAVs can only be flown in adequate wind and weather conditions; this can cause limitations to their use. These weather conditions are also necessary to collect accurate data from a UAS, given that wind and other weather conditions can cause the camera connected to the UAV to shake. However, MassDOT procedures require that data be collected under ideal weather conditions for the speed setting process; given this use, this limitation should not be an issue for the data collection necessary for the speed setting process (*15*).

Studies have been completed using UAS for traffic surveillance, as well as roadway incident monitoring (*8*, *9*). When utilizing UAS for traffic monitoring, it is important to

consider data collection accuracy. The most basic parameter is the number of pixels in a video of the recorded area; as pixels increase, accuracy increases (*7*). In a study completed in 2016 by Wang et al., vehicle detecting for traffic monitoring was found to be most accurate when the UAV's altitude was within the range of 100 meters (328 feet) to 120 meters (393 feet). When the altitude increased from 120 meters to 150 meters (492 feet), the accuracy of tracking decreased from approximately 99.8 percent to 96.1 percent (*8*). Per FAA Part 107 regulations, UAVs may not operate 400 feet above the highest structure in its vicinity, so flying below 400 feet when recording is optimal in this regard. Wang et al. utilized a particular method to find these accuracy results; this method utilized three image features jointly to detect and track vehicles: edge, optical flow, and local feature point (*8*). This specific method was designed for vehicle detection and tracking to improve efficiency and accuracy. Video stabilization applications can increase accuracy of the tracking data (*7*).

2.7.2 Static Aerial Image Processing

To collect more detailed information at a specific location, mounted video cameras can be placed to record the roadway. These devices are used in conjunction with video image processor systems to detect vehicles as well as specific data, such as speed. This technology has been understood for several years (*47*, *48*). Processors analyze successive video frames to extract this data using algorithms and object tracking (*48*). Object tracking in video is often separated into three distinct areas: objection representation, object detection/recognition, and object tracking (*12*).

2.7.3 Commercial Video Processing for Traffic Data Collection

Many companies have commercialized automated vehicle tracking and traffic data processing across the globe. Miovision, for example, offers TrafficLink Detection to customers. This involves the installation of a single 360-degree camera at an intersection, and provides always-on turning movement counts, lane-by-lane volumes, and classifications for vehicle type (*49*). Other companies, such as Marr Traffic, Mike Henderson Consulting LLC, and L2 Data Collection Inc., collect similar data collection through the use of mounted video cameras (*50–52*).

One company that completes UAS-specific video aerial image processing for traffic data is DataFromSky (*53*). Their system only requires aerial video and a description of the scene that was recorded to be able to provide trajectories of every detected vehicle in the video. These vehicles are then labeled in the video by a unique ID, along with a record of the vehicle's position, speed, and acceleration. DataFromSky is also able to analyze vehicle trajectories to calculate traffic flow characteristics that are defined by the 2010 Highway Capacity Manual (*14*). Additionally, they are able to provide gap acceptance, critical gaps, capacity estimations, average speed, and vehicle counts. DataFromSky has partnered with several companies, including Traffic Analysis & Design, Inc. in the United States, who serve the states of Minnesota and Wisconsin. They have also cooperated with PTV Group to export results from DataFromSky and input them into PTV Vissim. These results include traffic counts, vehicle classification, turning movements, speeds for model calibration, accelerations, travel times (defined between two gates), and gap in seconds (*53*). DataFromSky's capabilities with UAS video data show that the range of possibilities today for using UAS for traffic monitoring is extensive.

2.7.4 Commercial Applications

UAS are increasingly being employed for a number of applications outside of traffic monitoring, within and outside the field of transportation. Given the large cost savings that is possible with using UAS over manual work, along with improved safety, time saving, and a reduced need for lane closures (if transportation-related work), they have been deemed as highly beneficial for industry tasks and projects. According to a survey report from AASHTO in 2016, bridge inspection costs can be saved when using UAVs over manual inspections. It was estimated that over $4,000 could be saved during a bridge deck inspection using the technology (*6*). Additionally, UAS imagery has been found to be superior to conventional aerial photography because the camera on the UAV can be closer to the subject. This can be useful for surveying large areas, roadway mapping, lane marking data collection, and crash reconstruction (*11*, *54*). It is estimated that using a UAS to document a crash scene decreases the time spent on the roadway by 80 percent and the time spent taking measurements by 65 percent compared to traditional methods (*11*). In 2013, the Traffic Support Unit in the Highway Safety Division in Ontario mapped major collision scenes in just 22 minutes, on average, using UAS (*11*). This increases the safety of first responders, reduces the economic impact on drivers from lost time, and increases the safety of the roadway through the reduction of possible secondary collisions.

In 2018, the FAA released data on registered UAS throughout the United States. From the launch of online registration in the second quarter of 2016 to the end of 2017, more than 110,000 commercial operators had registered their equipment (*55*). In Figure 2 below, this data is presented in terms of industry. This shows that, while there are many

application of UAS in the transportation industry, other industries are utilizing these devices and exploring their possibilities as well.
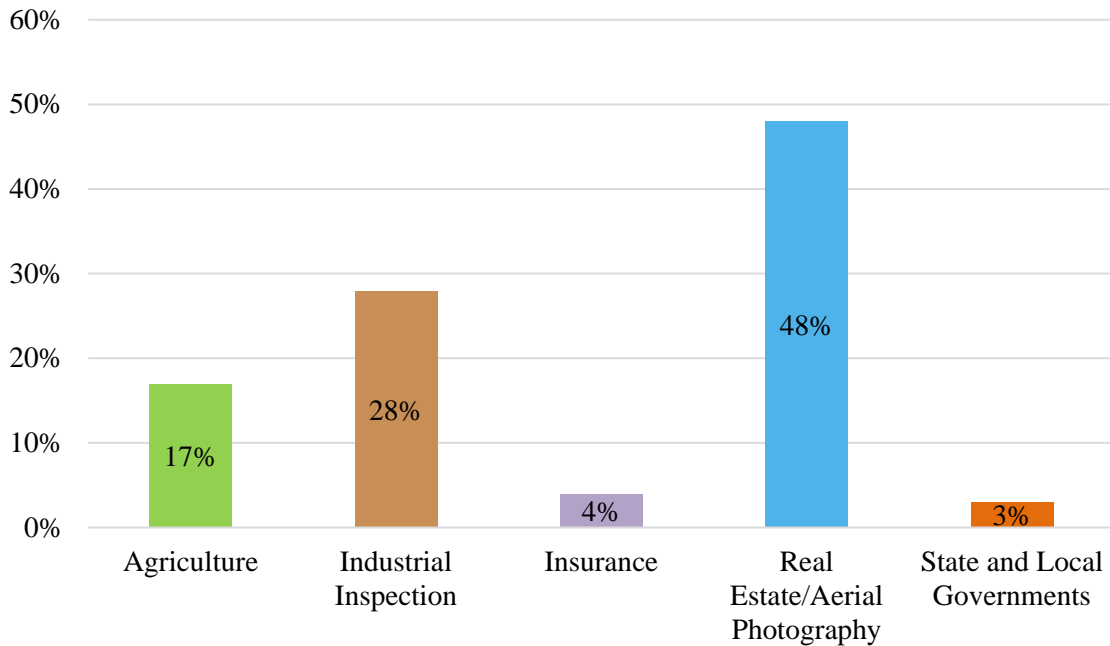
Figure 2: Present uses of non-model UAS (adapted from FAA (55))

2.7.5 Hobbyist Use

With UAS use increasing for commercial purposes, hobbyist, or recreational, use is also increasing. According to the FAA, in June 2018, UAS registration hit 1,000,000, including 878,000 hobbyist pilots (where one identification number is received for all of the UAVs one individual owns) and 122,000 commercial, public, or other UAS (which are individually registered) (*56*). This number has grown significantly since 2016, when the FAA online registration system went live for UAS. In 2016, nearly 300,000 owners registered their UAS (*57*). This registration process is discussed in the following section.

2.8   Existing UAS Regulations

UAS regulations in the United States are defined by the FAA, granted by the Federal Aviation Act of 1958 which gives the FAA authority over use of airspace in the United States (*58*). Past FAA regulations for UAS were the 1981 Advisory Circular and 2012 Section 333 of the FAA Modernization and Reform Act (FRMA) (*59*, *60*). While no longer governing, these regulations set safety standards for model aircrafts and created a basis of rules for public drone use. Today, the governing regulation for UAS use in the United States is Part 107 of the Federal Aviation Regulations (*61*). Established in 2016, this recent regulation outlines specific rules for small UAS operation for non-hobbyist use (*62*). The following regulations pertaining to this research are summarized below (*61*, *63*):

- Unmanned aircraft must weigh less than 55 pounds.

- Unmanned aircraft must be within visual line-of-sight of the remote pilot or the visual observer, unaided by any device other than corrective lenses.

- Operations are only permitted during the daylight, or civil twilight (30 minutes before official sunrise to 30 minutes after official sunset) with appropriate anti-collision lighting.

- Use of visual observer is an option, but not required.

- Maximum altitude of 400 feet above ground level (AGL) or flown within 400 feet of a structure.

- To qualify for a remote pilot certificate, a person must:
    - Pass an aeronautical knowledge test at an FAA-approved knowledge testing center; or hold a Part 61 pilot certificate other than student pilot, complete

a flight review within the previous 24 months, and complete a small UAS online training course provided by the FAA.

- o Be vetted by the Transportation Security Administration.
- o Be at least 16 years old.

- Remote pilot in command must conduct a preflight check of the small UAS to ensure it is in a condition for safe operation before flight; FAA aircraft requirements for UAS are not existent.

- Operation over human beings are not permitted, unless that human being is directly participating in the operation of the small unmanned aircraft or located under a cover structure or inside a stationary vehicle that can provide reasonable protection from a falling small unmanned aircraft.

- Part 107 does not apply to model aircraft.

As stated in the last summarized bullet point in this list, hobbyist pilots are not required to follow Part 107 rule. Hobbyists, however, are required by the FAA to register their UAVs online. While they are able to own as many UAVs as they like, each aircraft must visibly display the owner's contact information and unique registration number (*62*). This registration is valid for three years and costs $5 per individual owner. While there are no specific rules or regulations for hobbyists, under interim final rule, the FAA can impose a civil penalty of up to $27,000 or criminal penalties of up to $250,000 and three years in prison for noncompliance of UAS registration (*62*).

2.8.1 State Level UAS Regulations

In addition to federal regulations, state governments have begun to implement UAS regulations. As of 2017, at least 38 states considered legislation related to small UAS (*64*). A summary of these regulations is shown below in Table 2.

*Table 2: Summary of state small UAS regulations as of 2017 (information from (*64*, *65*))*

	Preempts localities from regulating UAS in some way	Privacy regulations enacted	Specific regulation related to hobbyist UAS operation	Criminal penalties for misuse	Prohibits the possession or use of weaponized UAS by anyone	Critical infrastructure protections enacted	Prohibits the use of UAS for hunting and/or fishing
Alaska		X					
Arizona	X			X		X	
Arkansas		X		X		X	
California		X		X			
Colorado							
Connecticut	X						
Delaware	X			X		X	
Florida	X	X		X	X		
Georgia	X		X				
Idaho		X					X
Illinois		X					
Indiana		X		X			X
Iowa		X					
Kansas		X		X			
Kentucky				X			
Louisiana	X	X		X		X	
Maine		X					
Maryland	X						

	1	2	3	4	5	6	7
Michigan	X	X	X	X			X
Minnesota							
Mississippi		X		X			
Montana	X	X		X			
Nevada		X		X	X	X	
New Jersey	X	X		X			
North Carolina		X	X	X	X		X
North Dakota		X					
Oklahoma						X	
Oregon	X	X		X	X	X	X
Rhode Island	X						
South Dakota		X		X			
Tennessee		X		X		X	
Texas	X	X		X		X	
Utah	X	X	X	X	X		
Vermont		X	X	X	X		
Virginia	X	X		X			
West Virginia							X
Wisconsin		X		X	X		

Many states have enacted legislature related to UAS; specifically, states have policies and regulations on UAS flown near critical infrastructure such as pipelines, water treatment facilities, and chemical manufacturing facilities. However, no state legislature nor federal regulations discuss UAS operations near roadways or drivers. To date, safety concerns related to UAS have been primarily related to privacy.

2.8.2 Global UAS Regulations

Countries around the world have begun developing their own UAS regulations as well. For example, in Canada, UAS are regulated through Transport Canada, the department responsible for regulating transportation (similar to the U.S. Department of Transportation). If a UAS is operated for personal hobby use and weighs less than 35 kilograms (approximately 77 pounds), the operator does not need to obtain permission to fly it. However, if the UAS is being used for work or research, the operator typically must apply for a certificate (*62*). Canada has regulations on UAS use near vehicles, as described in Table 3.

Globally, little literature was found on UAS regulations in the vicinity of roadways, where UAS may cause distraction. The following table below summarizes selected global regulations of UAS near roadways, vehicles, or people. While gathering this research, it was found that many countries had regulations to prohibit UAS from flying over any person not involved in the flight. However, less country regulations discussed UAS flight near public roadways. No regulation discussed the potential of UAS as a distraction to drivers.

Table 3: Selected UAS regulations from other countries pertaining to UAS flight near roadways, vehicles, or people

Canada (*66*) *(recreational use)*	"Fly your drone: • below 90 m [295 feet] above the ground • at least 30 m [98 feet] away from vehicles, vessels and the public (if your drone weighs over 250 g [0.55 lbs] and up to 1 kg [2.2 lbs] …"
Ireland (*67*)	"A person who has charge of operation of a small unmanned aircraft which has a mass of less than 25 kilograms [55 lbs], without fuel but including any articles or equipment installed in or

	attached to the aircraft… shall not allow such an aircraft to be flown, unless otherwise permitted by the authority and subject to such conditions as are required by such permission: … (*c*) at a distance less than 30 metres [98 feet] from a person, vessel, vehicle or structure not under the direct control of the operator …"
Japan (*68*)	"Any person who intends to operate a UA [Unmanned Aircraft]/Drone is required to follow the operation conditions listed below, unless approved by the Minister of Land, Infrastructure, Transport and Tourism. … (iii) Maintenance of 30m [98 feet] operating distance between UAs/Drone and persons or properties on the ground/water surface."
South Africa (*69*)	"3. Do not fly RPA [Remotely Piloted Aircraft] 50m [164 feet] or closer from: a. Any person or group of persons (like sports fields, road races, stadiums, schools, social events, etc.) b. Public road c. Any property without permission from property owner"
Zimbabwe (*70*)	"No person shall operate an RPA [Remotely Piloted Aircraft] over an aerodrome, or an aerodrome's approach path, or a public road or along the length of a public road or at a distance of less than 30m [98 feet] from a public road unless: a) such person is the holder of an ROC [Remotely Piloted Aircraft System Operator's Certificate] and the operation has been approved by the Authority in the operator's operations manual; b) reasonable care has been taken to ensure the safety of road users and pedestrians in the event of loss of control of the RPA."

2.9 Driving Simulator Research

Driving simulators offer a safe and effective method for examining driver performance in a controlled environment. Many of the studies previously discussed were completed in high-fidelity driving simulation environments, indicating the possibility to effectively explore external distractions through simulation (*41*, *43*, *44*). Additionally, a study completed by Elsa et al. found driving simulators to be effective in differentiating behaviors of novice drivers and experienced drivers, and, more specifically, these authors argue that in the case of hazard anticipation, speed management, and attention maintenance, driving simulators generalize the real world (*71*).

CHAPTER 3: METHODOLOGY

A series of research tasks were developed based upon the existing literature. An experimental design was created to evaluate the effects of UAS height, operator presence, and UAS familiarity on driver performance. The following section outlines the tasks that were employed to address the research objectives.

3.1 Literature Review

A comprehensive literature review was conducted to understand the potential use of UAS for traffic monitoring and other uses in the vicinity of roadways, current UAS regulations, safety implications of external distractions, and driving simulator research effectiveness. Gathering research related to current and potential future UAS use was a key aspect of this research to understand realistically how UAS may be flown in the vicinity of roadways in the future. This section of the methodology outlined the potential of UAS flight height and remote pilot and visual observer locations when flying in the vicinity of roadways. Potential for driver distraction due to UAS flight at varying heights and observer locations appeared to not have been published to date. Throughout the process of this research, the literature review was continued as the project developed.

3.2 Simulation Study Development

A full driver simulator study was developed to study the outlined research objectives and questions. In short, the effects of driver distraction due to UAS and their remote pilot and observer presence were aimed to be evaluated. As discussed in the literature review, full immersion driving simulators have been effective in simulating real-world environments. The following sections outline the main equipment that was utilized in this study, all of

which is located in the Human Performance Laboratory on the University of Massachusetts Amherst campus.

3.2.1 Full Immersion Driving Simulator

The Human Performance Lab (HPL), located in Engineering Laboratory I on the University of Massachusetts Amherst campus, includes a fixed base driving simulator. This simulator uses Realtime Technologies, Inc. (RTI) simulation software. In this environment, the participant in the automobile is able to move through the virtual world using the vehicle controls as if in a real automobile. Further, the visual representation of the virtual roadway changes appropriately in response to drivers' actions, as in the real world. Visually, the simulator is a full car cab (4-door) with nine visual channels. The car itself is a 2013 Ford Fusion sedan, and allows the driver to operate the normal accelerator, brake, steering, transmission selection, and signaling controls with the simulator responding accordingly. This simulator is pictured in Figure 3.

Figure 3: Full immersion driving simulator

The five forward channels, or screens, plus the rear channel creates a 330 degree field-of-view (FOV). This wide FOV is accomplished by connecting six flat screens with scenes provided by six high resolution projectors. The front five projectors provide a resolution of 1920 by 1200 pixels, while the rear project provides a resolution of 1400 by 1050 pixels. The rear scene can be viewed through the in-cab rear-view mirror. The side-view mirror, virtual dashboard, and 17-inch touch screen center screen are simulated with LCD panels. A 5.1 channel audio system, external to the cab, provides the environmental sounds in the driving environment, including traffic, passing vehicles, and road noise. An internal audio system provides engine sounds and vibrations, as in a real world environment.

Outside of the participant simulated environment, an operator station provides a duplicated visual center channel screen and a control monitor. This allows the experimenter

to observe the driver's speed and other variables. Empirical data can be captured within the software of the simulator. This includes data of velocity, lane offset, and position (X,Y,Z).

3.2.2   Eye Tracking Device

The portable lightweight eye tracker device is a Mobile Eye, developed by Applied Science Laboratories. This device has an optical system consisting of an eye camera and an in-color scene camera mounted on a pair of safety goggles. The images extracted from these two cameras are interwoven and recorded, and the eye movement data are converted to a crosshair, representing the wearer's point of gaze. This crosshair is superimposed on the scene video, presenting the location of the gaze. The remote recording system is battery-powered and capable of recording up to ninety minutes.

3.3   Driving Simulator Scenario Design

All driving scenarios were developed in the HPL on the University of Massachusetts Amherst campus using RTI software. A total of nine micro-scenarios were design for this study, with one of these scenarios being a practice drive. Each scenario took approximately two minutes to complete. With the exception of the practice drive, each drive was developed in the same base model to minimize any potential change in performance due to other variables besides the ones being studied. This base scenario was developed with the following conditions:

- Zero vehicles in the driver's lane, following or ahead
- Two scripted vehicles in the opposing lane
- Speed limit of 35 miles per hour, presented at the beginning of the scenario
- Rural area with minimal trees and structures
- Clear skies

- Daytime

The practice scenario included these same base conditions as the base scenario. However, the design of the practice and base scenarios differed. This base scenario placed drivers at the beginning of a right turn, providing time for drivers to gain speed moving straight before taking the right curve. A screenshot of the beginning of this drive is shown in Figure 4 below.

Figure 4: Placement of participant at beginning of each drive in base scenario

After this curve, a scripted, or programmed, larger truck drove past the participant at the speed limit of 35 miles per hour in the opposite lane. This part of the base drive is shown in Figure 5.

Figure 5: Participant view after curve in base scenario

After the passing of this vehicle, another smaller vehicle, a car, was then seen in the distance, before approaching and passing the participant. After driving forward after the curve, the participant passed through an empty stop-controlled intersection, with only the adjacent two connecting streets with stop control. Finally, the scenario ended with a sign on the central screen asking drivers to stop and place the car in park to end the scenario. The simplicity of this scenario allowed for specific independent variables to be evaluated. These variables are presented in Table 4.

Table 4: Driving simulator independent variables

Variable	Type	Levels
UAV Height	Multi/Categorical	20 feet AGL, 40 feet AGL, 60 feet AGL
Operator Presence	Binary	Yes/No
UAV Roadside Location	Binary	Left/Right
UAV Location - Up/Downstream	Binary	Upstream/Downstream

The pilots in this experiment were initially created in Google SketchUp, before being imported into the RTI software to incorporate into the scenarios. The pilots each stood approximately 6 feet tall and always were positioned in the same stance throughout all scenarios. The UAV utilized in this research was the same design as the one in the study completed by Hurwitz et al. (*2*). Given this similarity, this research can be compared to a higher degree to the novel research on driver distraction due to drones, completed by Hurwitz et al. The UAV and pilots are shown in Figure 6 and Figure 7.

Figure 6: Close up of drone pilots

Figure 7: UAV at 20-foot altitude with pilots

The binary variables of UAV roadside location allowed for this study to expand to the different locations that UAVs may be seen, either immediately adjacent to the left of

the roadway or the right. Further, the binary variable of UAV location, upstream or downstream, allowed for this study to analyze the differences in driver performance if the UAS is present soon after a curve or further away from a curve on a straightaway. From these independent variables, eight main scenarios were developed, based on operator presence and UAV height alone, including the control scenarios. From these main scenarios, a total of 26 unique scenarios were built, which included the UAV roadside location and UAV location, upstream or downstream, variables. In each scenario with a UAV, the UAV was placed at the specified height immediately adjacent to the main roadway, either to the left or right, per FAA Part 107 regulation that does not allow UAS to be flown above people (*61*). Additionally, operator presence in each scenario including this variable included two people: one as the operator and the other as the visual observer. This was decided based upon the literature review, provided that most commercial UAS operations would include at least two people. Each developed scenario is presented in Table 5.

Table 5: Driving simulator scenario descriptions

Scenario Label	Operator Presence	UAV Height (AGL)
1A	Yes	20 feet
1B	Yes	40 feet
1C	Yes	60 feet
2A	No	20 feet
2B	No	40 feet
2C	No	60 feet
3A (in Latin Square)	No	*No UAV*
3B (final scenario)	No	*No UAV*

It is important to note that scenarios 3A and 3B are the same scenarios, just placed in different points of scenario run order. Given the low number of main scenario drives, this study was completed as a within-subject design for the variables of operator presence and UAV height. The study expanded further in the form of a between-subject design for the variables of UAV roadside location and UAV location, upstream or downstream. To minimize any potential bias due to scenario order, this study utilized the Latin Square model. Only seven out of the eight scenarios were included in this model as Scenario 3B was added to the end of each scenario run, no matter the Latin Square order, to compare the control scenario (3) within the Latin Square to the control scenario at the end of the study. This allows further exploration of how repeated UAS presence may influence driver performance even in scenarios where they are not present. In total, the design of this experiment was designed for twenty-eight participants, which would allow the Latin Square model to be run through twice. Table 6 below presents the run order for the participants.

Table 6: Scenario run order following Latin Square model

Participant Number	Scenario Order							
1/15	1A	1B	3A	1C	2C	2A	2B	3B
2/16	1B	1C	1A	2A	3A	2B	2C	3B
3/17	1C	2A	1B	2B	1A	2C	3A	3B
4/18	2A	2B	1C	2C	1B	3A	1A	3B
5/19	2B	2C	2A	3A	1C	1A	1B	3B
6/20	2C	3A	2B	1A	2A	1B	1C	3B
7/21	3A	1A	2C	1B	2B	1C	2A	3B
8/22	2B	2A	2C	1C	3A	1B	1A	3B
9/23	2C	2B	3A	2A	1A	1C	1B	3B

10/24	3A	2C	1A	2B	1B	2A	1C	3B
11/25	1A	3A	1B	2C	1C	2B	2A	3B
12/26	1B	1A	1C	3A	2A	2C	2B	3B
13/27	1C	1B	2A	1A	2B	3A	2C	3B
14/28	2A	1C	2B	1B	2C	1A	3A	3B

In addition to this within-subjects study design including the variables presented in Table 5, the between-subject variables presented below in Table 7 are included in the study. These variables included as between-subject allows the UAV and their operators to be placed at different locations in the scenarios, as to minimize bias.

Table 7: Between-subject scenario labels

Scenario Sublabel	UAV Upstream/Downstream Location	UAV Roadside Location
UR		Right
UL	Upstream	Left
DR		Right
DL	Downstream	Left

The run order with the location specifications is shown below in Table 8. These sublabels were built from their own Latin Square model and built into the order in Table 6. Manually using Microsoft Excel, this run order of the sublabels were manually distributed to be included with each scenario (1A, 1B, etc.) the same number of times. To be exact, each sublabel was included seven times, out of all scenarios of the 28 subjects. To note, location sublabels were not included in the scenarios where UAV and operators were not present (3A and 3B).

Table 8: Full scenario run order with sublabels

Participant Number	Full Scenario Order							
1	1A UR	1B DL	3A	1C DL	2C DR	2A UR	2B UL	3B
2	1B UL	1C DR	1A UR	2A DL	3A	2B UL	2C DR	3B
3	1C UL	2A DR	1B UL	2B DL	1A DR	2C UR	3A	3B
4	2A DL	2B UR	1C DL	2C UL	1B UR	3A	1A UL	3B
5	2B UR	2C UL	2A DL	3A	1C DR	1A DL	1B UL	3B
6	2C DR	3A	2B DL	1A UL	2A UR	1B DR	1C DL	3B
7	3A	1A UL	2C UR	1B UL	2B DL	1C DR	2A UR	3B
8	2B DL	2A UL	2C DR	1C UL	3A	1B UR	1A UL	3B
9	2C UR	2B UL	3A	2A DL	1A DR	1C UL	1B DR	3B
10	3A	2C UL	1A DR	2B UR	1B DR	2A UL	1C DR	3B
11	1A UR	3A	1B DL	2C UL	1C UR	2B UL	2A DL	3B
12	1B DR	1A UR	1C DR	3A	2A DR	2C DL	2B UR	3B
13	1C UR	1B UL	2A DL	1A DR	2B UL	3A	2C DR	3B
14	2A UR	1C DR	2B UR	1B DL	2C UL	1A DL	3A	3B
15	1A UL	1B UR	3A	1C UL	2C UR	2A DR	2B DL	3B

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16	1B DL	1C UR	1A DR	2A UR	3A	2B DL	2C UR	3B
17	1C UR	2A UL	1B DL	2B DR	1A UR	2C UL	3A	3B
18	2A UR	2B DR	1C UR	2C DL	1B UR	3A	1A DL	3B
19	2B DR	2C UR	2A UL	3A	1C DL	1A UL	1B DR	3B
20	2C DL	3A	2B UR	1A DR	2A UL	1B DR	1C UR	3B
21	3A	1A DL	2C UL	1B DL	2B DR	1C UR	2A UL	3B
22	2B UL	2A DR	2C UR	1C DL	3A	1B UR	1A DL	3B
23	2C DR	2B DL	3A	2A UR	1A DL	1C DL	1B DR	3B
24	3A	2C DL	1A UR	2B DR	1B UL	2A DR	1C UL	3B
25	1A DL	3A	1B UR	2C DL	1C UL	2B UR	2A DR	3B
26	1B UL	1A DR	1C DL	3A	2A DL	2C DR	2B UL	3B
27	1C DR	1B DL	2A UL	1A UR	2B DR	3A	2C DL	3B
28	2A DR	1C UL	2B DR	1B UR	2C DL	1A UL	3A	3B

Dependent variable data that was obtained from these simulator scenarios is presented in Table 9 below. As previously described in the equipment descriptions, speed and lateral movement data is collected through the simulator output, and eye glance video is provided with the use of the eye tracker device.

Table 9: Dependent variables of driving simulator experiment

Variable	Output
Speed of Driver	Continuous
Lateral Movement of Driver	Continuous
Eye Glance Behavior	Continuous/Binary

3.4 Static Evaluation Design

A static evaluation was created and utilized in Qualtrics, an online comprehensive survey software tool. The main purpose of this tool was to evaluate participants of the driving simulator post-drive to gather their demographic information, obtain their comments on the drive scenarios they completed, and obtain their knowledge and opinion of drones, or UAS. A full version of this survey is provided in Appendix B: Static Evaluation, with logic. The survey began with demographic information questions of age, gender, driving experience, and eye glasses/contacts requirements for driving. The age groups were defined as 18 to 24 years old, 25 to 45 years old, and 46 to 75 years old, as these groups are commonly reported in literature. Following, participants were asked to provide any additional comments they had on the simulator portion of the study they just completed in short answer form. This was to provide participants with the opportunity to discuss their experience in the simulator and any comments they may have, potentially including comments of UAS and operators, without first influences the participants to think about those topics. Next, participants were asked to write comments on the simulator portion of the study they just completed on the drone, or Unmanned Aerial System (UAS), presented during some of the scenarios. It also asked to include any comments on the pilots/operators on the side of the roadway. This question was stationed to provide participants the

opportunity to recall the scenarios and specifically discuss the UAS and operators if they had not done so already. Providing this question in short answer format as well allowed participants to communicate freely about their experiences and thoughts on UAS and their operators near roadways without any prejudice.

After these preliminary questions, the static evaluation then aimed to gain information on the participant's view and knowledge of UAS specifically. The following page of the survey included an image of a flying drone and asked participants, in short answer form, what their thoughts on the use of drones were, as well as, in yes or no form, if they had ever seen a drone before. If they answered "yes" to this question, participants were brought to the next question. If they answered "no," participants were brought to "Question 17" as the following questions would not pertain to them. This question is described later. Given that a participant answered "yes" to the question of if they had seen a drone before, participants were asked if they had seen a drone in flight near a roadway. If the participant answered "no" to this question, participants were brought directly to "Question 16," described later, as the questions in between would not pertain to that participant. Further, if the participant answered "yes" to the question of if they had seen a drone in flight near a roadway, they were then asked when they had seen a drone in flight. For this question, participants were provided with the following response options, and they were asked to "choose all that apply":

- While driving a vehicle
- While riding as a passenger in a vehicle
- While riding a bicycle
- While walking on a sidewalk or walking path

- Other (please specify) _____-

This question was included to evaluate how often UAS are flown near roadways or walking paths; at least, how often they are flown in these scenarios and noticed by people. If the participants chosen options for this question included "while driving a vehicle," then the participant was asked the following question. Otherwise, this immediate next question was skipped. This question, presented only to those who had seen a flying UAS while driving, was presented to gain feedback on the drivers immediate thoughts on that moment to understand how drivers perceive UAS in the real world when in a driving environment. This question asked what the driver's initial thoughts were when they saw the drone in the sky while driving in the real world. The participant was provided with the following options and were asked to "choose all that apply":

- Wondered what it was doing/what it was there

- Was nervous that it might hit your vehicle

- Wondered who was flying the drone

- Ignored the drone; didn't have any thoughts about it

- Other (please specify) _____

Following this question, regardless of the answer, Question 16 was presented. This question was in short answer form and asked participants where they have seen a drone in flight. Question 17 then asked a "yes" or "no" option question: "Should drones be allowed to be flown near roadways?". Question 18 was the final question of the survey, and asked participants to comment on their reasoning for stating "yes" or "no" in short answer format. Participants were then thanked for participating in the study and to let the researcher know

that they are finished taking the survey. These last few questions allowed for participant views on UAS to be collected.

3.5   Participants

A total of 29 licensed drivers participated in this study. Of those participants, 28 fully completed the study, and, thus, only the data from those completed participants was analyzed in the analysis portion of this study. One participant was unable to complete the study as the eye tracker was unable to appropriately calibrate to their eye. Full demographic data of the participants is presented in Table 10.

Table 10: Driving simulator study participant demographics

Age Range	Frequency	Percent of Participants
18-24	18	64.3%
25-45	6	21.4%
45-75	4	14.3%
Gender		
Female	14	50%
Male	14	50%
Driving Experience		
Less than 5 years	8	28.6%
5 to 9 years	12	42.9%
More than 10 years	8	28.6%

3.6   Procedure

The experiment consisted of one session in the HPL at the University of Massachusetts Amherst of approximately 45 minutes. After Institutional Review Board (IRB) protocol approval of the study was obtained, participants were recruited through flyers positioned throughout the University of Massachusetts Amherst community and email to the HPL

respective email lists for simulator study recruitment. As the eye tracker device is worn over the eye, only participants who did not require eyeglasses to drive were recruited. It is noted that drivers with contact lenses were permitted to participant in this study. To begin their participation, drivers were asked to review and provide their consent on a consent form. A copy of this form is provided in Appendix C: Participant Forms. For their participation in this research, drivers were compensated $20. If participants at any point in the study after signing the consent form aborted the experiment due to simulator sickness or for any other reason, they were compensated the full $20.

After signing the consent form, participants were asked if they understood everything included in the form and if they had any questions. At that point, after it was clarified they understood the task and any questions were answered, the participant was then asked to enter the simulator vehicle. The eye tracker device was then positioned on the participant accordingly, and was calibrated. After successful calibration, the participant then completed a practice drive and then their respective order of scenarios corresponding to their participant number, assigned by the researcher.

After all drives were completed, the participant was then asked to complete the post-drive static evaluation online, as previously outlined. This static evaluation, presented on a provided University-owned secure laptop, collected participant demographic data, including their gender, age (in terms of range), driving experience, and eye requirement when driving, if applicable, before entering in the questions relating specifically to their simulator experience and background knowledge of UAS, or drones. After this static evaluation, participants completed the stipend voucher form, a copy of which is included in Appendix C: Participant Forms, and provided $20 as compensation. Finally, participants

were provided with a debriefing form. This form thanked the participant for completing the study, outlined the purpose of the studied, specified the confidentially of the data collected, and provided further contact information. A copy of this form is provided in Appendix C: Participant Forms.

3.6.1 Speed and Lateral Movement Data Analysis Techniques

Speed and lateral movement data, as collected in the driving simulator, is output in the form of a text file, with data collected every 0.016 seconds. Additionally, this data output includes drive identification number, participant identification number, distance, and x, y location data. For analysis, R version 3.4.3 was utilized. R is a statistical programming language for statistical computing. The data was grouped and labeled for easier data analysis, including the following: upstream/downstream, drone height, pilot presence, and left/right drone presence. With the goal of understanding the change in driver speed as they approached the drone/pilot, speed data was manipulated to be the change in speed from 328 feet (100 meters) before the drone/pilot to the drone/pilot location. This change in speed was additionally calculated for the scenarios without any drone/pilot, at the same locations, to compare to how drivers would perform without their presence. For the offset, or lateral movement analysis, this same change was calculated; specifically, the change in distance from the center lane before the drone/pilot to the location where they stood.

During the analysis phase, it was discovered that the upstream left scenario with the drone at 60 feet with the pilots did not include the pilots due to a technical error. Due to this, those seven scenario drivers were not included in the analysis. With the number of drive types, this specific missing scenario type did not negatively affect the final analysis.

Before statistical testing began on this data, the Shapiro-Wilk test of normality was performed, to check if the distribution of the data was not significantly different from a normal distribution (*72*). Given this, various statistical tests were chosen and performed on the data to check for statistical significance. The results of this analysis are shown in section 4.3.

3.6.2 Eye Tracking Analysis Techniques

Eye tracking data from the eye tracker is output in the form of video data with a red cross indicating the location of a participant's gaze. An example of this is shown in Figure 8. To analyze this data, a detailed Excel sheet was created to input the data into for each video and all
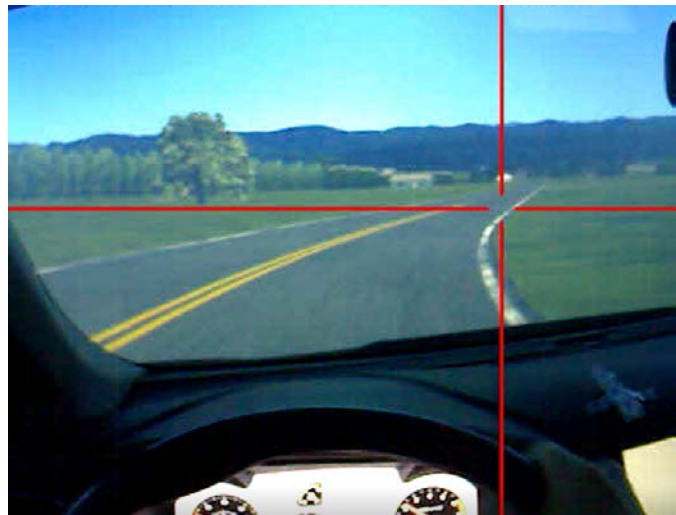
Figure 8: Snapshot of eye tracking video data

video reviewers underwent a training to maintain scoring consistency throughout all of the videos. Selected videos were analyzed twice by two reviewers to check this consistency in scoring. This collected data output in the form of the following: length of time participant looked at the drone, length of time participant looked at the pilot(s), length of time participant looked at either. From this, further data was extracted, including the average length of a gaze and the maximum length of gaze. This data was then input into R to analyze alongside the speed data. All results from this analysis are provided in sections 4.3 and 4.5. Due to some minor technical issues, three scenario videos were unable to be scored, or analyzed, by the reviewers and were not included in this analysis.

3.6.3 Static Evaluation Analysis Techniques

Static evaluation was output in the form of an Excel spreadsheet from Qualtrics. This data was input into R for analysis alongside the speed/lateral movement data and eye tracking data.

CHAPTER 4: FINDINGS AND RESULTS

The following chapter presents the results obtained from the literature review, driving simulator study, and static evaluation.

4.1   UAS Use in Transportation

As presented thoroughly in the literature review section, UAS have been utilized for a variety of different transportation uses. This is especially highlighted in section 2.7, where the use of UAS for traffic monitoring, structural inspection, roadway mapping, and lane marking data collection, to name a few, is presented. Given this information and supported by the increasing trend of registered UAS in the United States (*55*, *56*), it is can expected that UAS will continue to be utilized increasingly so near transportation infrastructure in the future. While UAS have the ability to create safer roadway environments through efficient and safe data collection techniques, this literature review also presented that drones has a potential to be distracting to drivers, as video billboards and winds farms can be.

4.2   Static Evaluation

Results of the static evaluation is presented in this section. As previously stated, this data was collected from each participant after the completion of the driving experiment. The gender split was 14 women and 14 men for this study. Figure 9 presents the breakdown of the age of the participants.
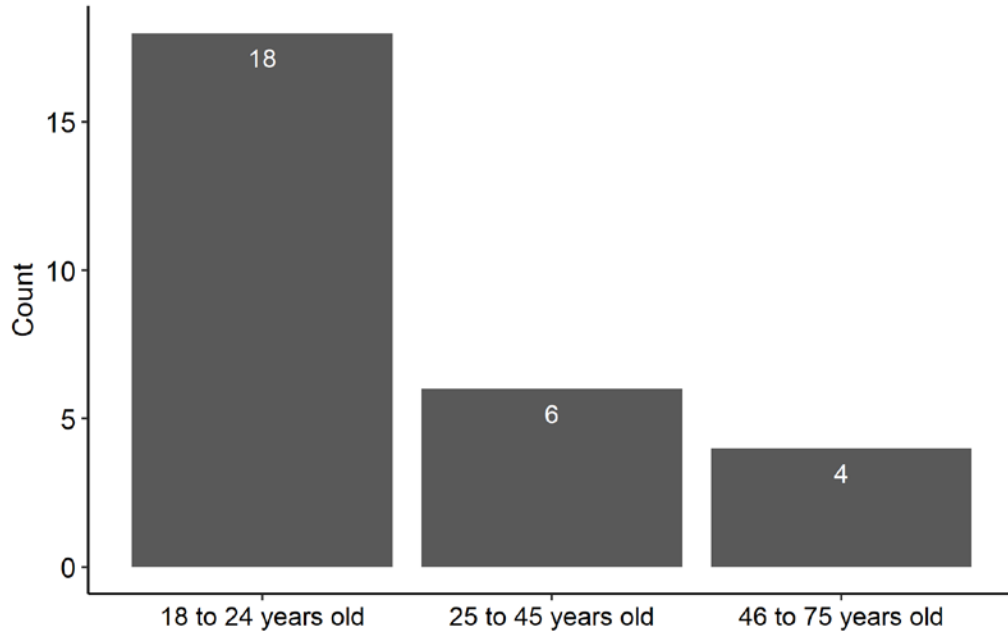
Figure 9: Count of participants in each age group

Again, this study is skewed towards the younger age group population as this study recruited from the Amherst, Massachusetts area, which has a large student population. Figure 10 presents the breakdown of years of driving experience among participants.
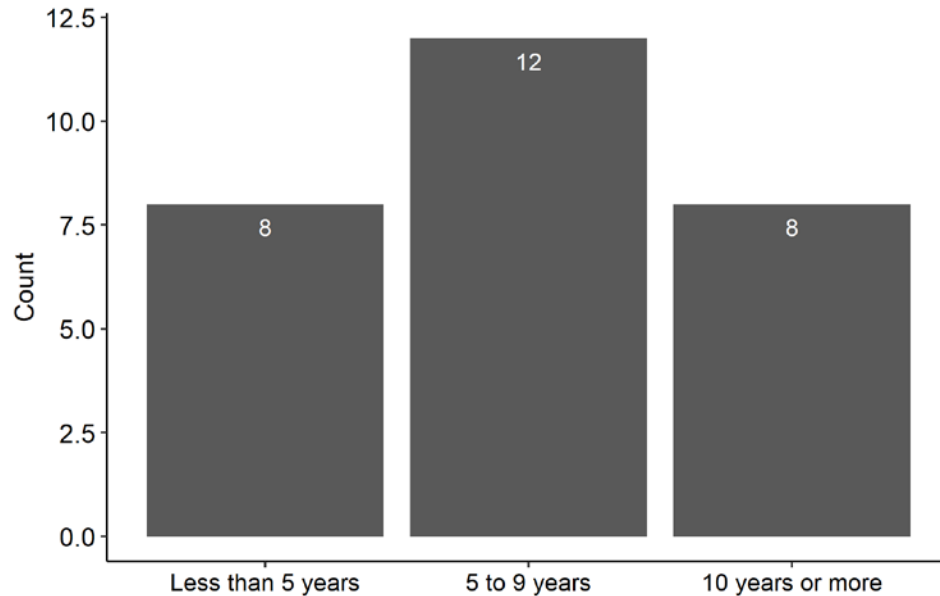
Figure 10: Years of driving experience among participants

The first question that participants were faced with after the demographic questions was the following question, which was optional: "Please write any additional comments you may have on the simulator portion of the study you just completed in the text box below." This question yielded answers relating to the driving simulator vehicle itself, among others that were unrelated to the study. Two answers to this question were related to the study purpose:

- *great use of drones!*

- *Noticed that I was looking for the drone which was present in some tests even if it wasn't there*

Following this question, the following was asked: "Please write comments on the simulator portion of the study you just completed on the drone, or Unmanned Aerial System (UAS), presented during some of the scenarios. Please also include any comments on the pilots/operators on the side of the roadway." The answers to this question, and all

short answer questions, are presented in Appendix D. The answers for this question varied, but were focused around distraction and participants taking their eyes off of the road to observe the drones or pilots. These answers are discussed in more detail in the discussion.

Next, the question "What are your thoughts on the use of drones?" was presented. Many participants stated that they thought drones were "cool" and "useful tools," but "need regulation" and "could be distracting." A full list of all of the answers to this question is presented in Appendix D.

Twenty-seven out of the 28 participants had seen a drone before. Of those who had, eight had seen a drone near a roadway, as presented in Figure 11. Further, of those eight, a breakdown of where those drones were specifically seen is presented in Figure 12.
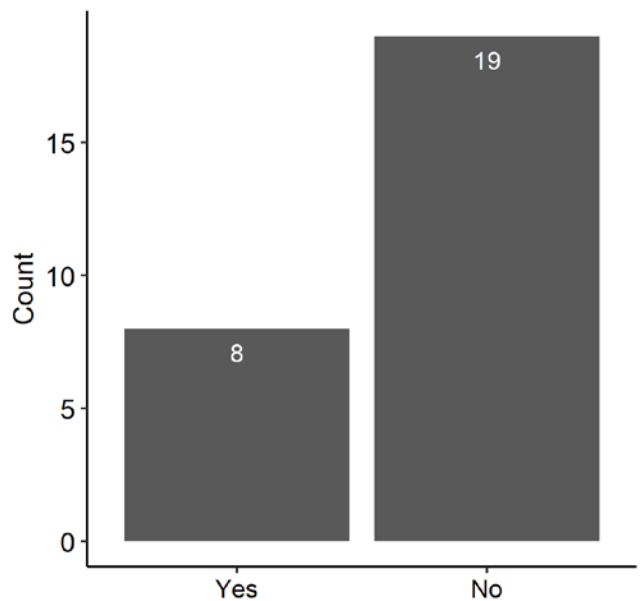
Figure 11: Count of responses to the question "Have you ever seen a drone in flight near a roadway?"
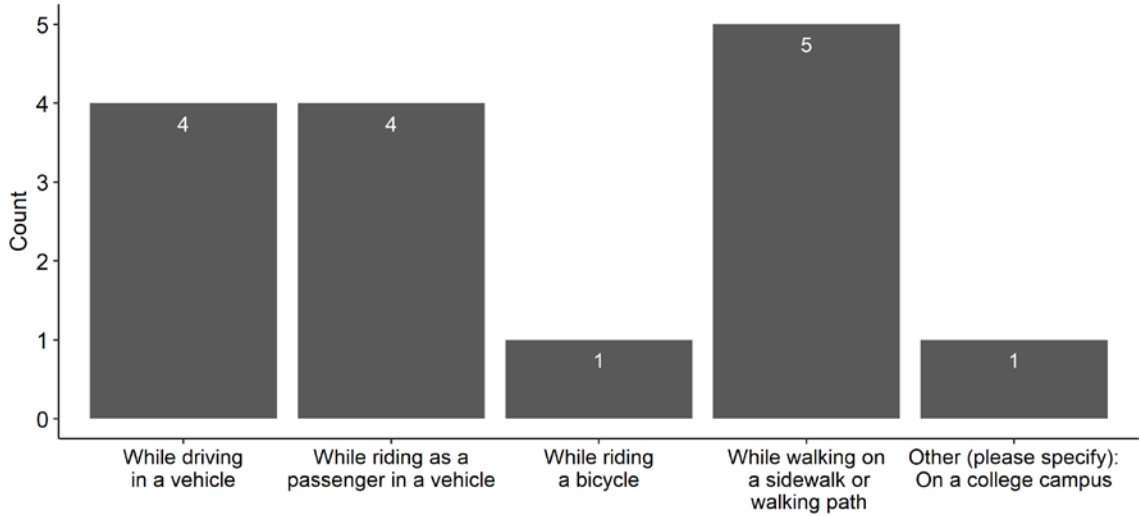
Figure 12: Count of responses to the question "When have you seen a drone in flight (Choose all that apply)" of the eight participants who had seen a drone

As shown in Figure 12, four participants had seen a drone near a roadway. Those participants then had to answer the following multiple choice question: "What were your initial thoughts when you saw the drone in the sky while driving in the real world? (Choose all that apply)." Figure 13 presents the responses to this question.
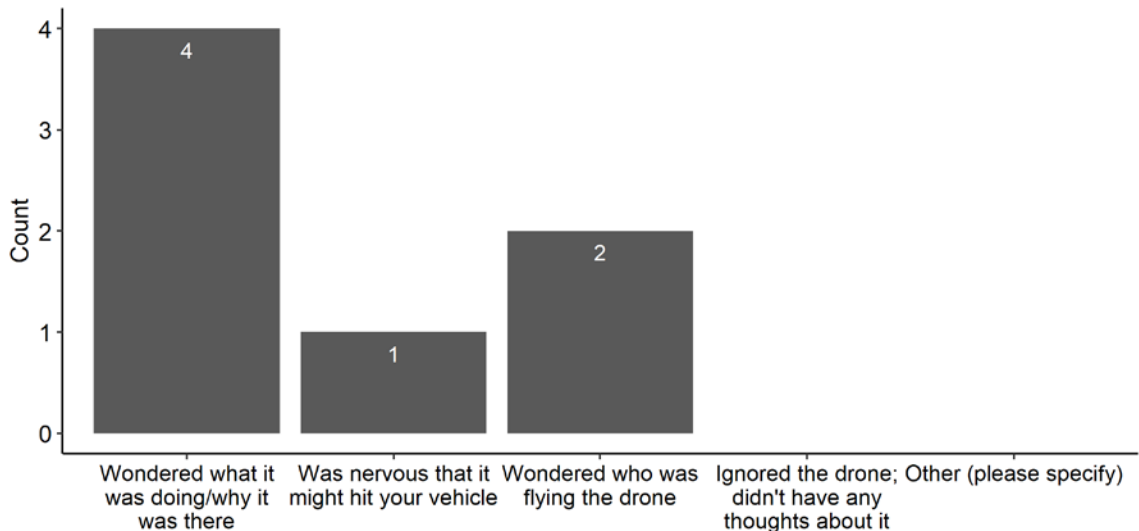
Figure 13: Count of responses to the question "What were your initial thoughts when you saw the drone in the sky while driving in the real world? (Choose all that apply)" of the four participants who had seen a drone while driving

Answers to the question "Where have you seen a drone in flight?" is in Appendix D. These answers varied from parks to participant's own homes, to beaches. Answers to the question of whether drones should be allowed to be flown near roadways is presented in Figure 14. Finally, short answer responses as to the participant's
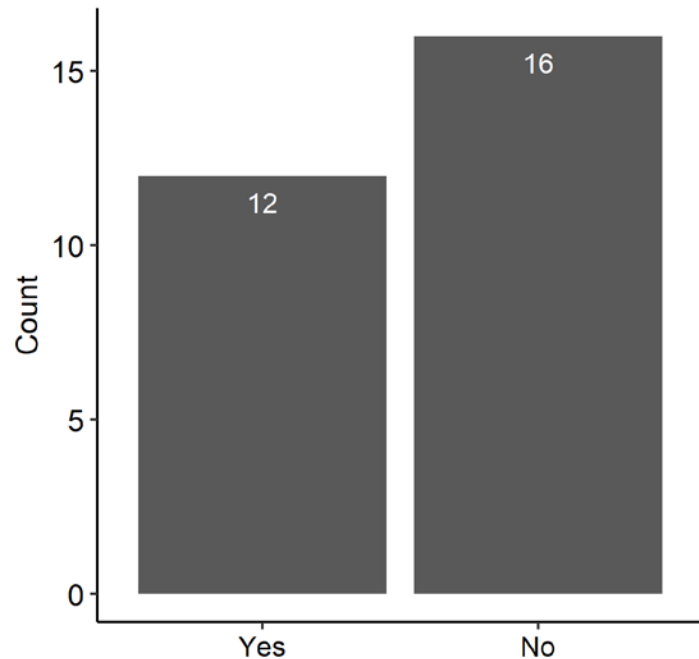
Figure 14: Count of responses to the question "Should drones be allowed to be flown near roadways?"

reasoning behind their decision to this question is presented in detail in Appendix D.

4.3   Speed Results

As previously mentioned, the Shapiro-Wilk test was utilized to determine if the change in speed data was normally distributed. This test revealed that the data was not normally distributed, and thus, the t-test could not be utilized to analyze this data. Instead, a Kruskal-Wallis rank sum test was performed. A Kruskal-Wallis test is often used a backup method for ANOVA when the independent variable is categorical, but the dependent variables are not normally distributed (*73*). This test performs a statistical analysis of the null that the dependent parameters of the provided distribution are the same in each independent group. The alternative is that they differ significantly in at least one group. Thus, if a Kruskal-Wallis test in this analysis proved relationships not significant (p-value > 0.05), it was accepted that the data groups were significantly different from one another and no further

analysis was performed. If the Kruskal-Wallis test proved the relationships to be significant (p-value < 0.05) then further analysis was completed using the Wilcoxon signed-rank test to determine which group(s) were significantly different. In this section, if the Wilcoxon signed-rank test was performed, then it can be assumed that there was a significant difference originally found through the Kruskal-Wallis test. The Wilcoxon test is a non-parametric test does not require that the data be normal and the null hypothesis taken as equal medians (*74*, *75*). In R, the pairwise Wilcoxon test and the Benjamini-Hochberg procedure to adjust the false discovery rate (*76*) was utilized in this analysis.

Demographic data was first analyzed with the change in speed data. Given the non-normality, and thus, use of the Wilcoxon test to analyze the data which uses the median to test for significance, the median change in speed is reported in the statistical data tables. The median is similar to the mean as it is a measure of central tendency, but is very insensitive to the presence of outliers (*77*). The median absolute deviation (MAD) is also presented in the data tables. Essentially, MAD represents the number of absolute deviations from the median (*77*). Both of these statistics are shown in Table 11 for all of the demographic data in relation to the change in speed.

Table 11: Statistical data of the change in speed for all demographic data

		Median Change in Speed (mph)	Median Absolute Deviation (MAD)
Gender	Female	0.779	3.34
	Male	0.70	2.71
Age Group	18 to 24 years old	0.792	3.29
	25 to 45 years old	0.745	2.90
	46 to 75 years old	-0.494	2.49

	Less than 5 years	0.770	3.34
Driving Experience	5 to 9 years	1.00	3.18
	10 or more years	-0.465	2.58

It was found that gender was not statistically significant (p-value of 0.55), but age and driving experience was. Specifically, there was significance between the age group of 18 to 24 years old and the age group of 46 to 75 years old. The p-values of the Wilcoxon test performed on the data is shown in Table 12.

Table 12: P-values of the differences in the change in speed due to age groups from Wilcoxon pairwise test

Age Group	18 to 24 years old	25 to 45 years old
25 to 45 years old	0.070	-
46 to 75 years old	**0.012**	0.234

Change in speed was significantly different for the 10 years or more driving experience group compared to both the 5 to 9 years group and less than 5 years group. These p-value results are shown in Table 13.

Driving Experience	5 to 9 years	10 years or more
Less than 5 years	0.518	**0.0004**
5 to 9 years	**-**	**0.0035**

Table 13: P-values of the differences in the change in speed due to driving experience from Wilcoxon pairwise test

For the independent variables of drone height and pilot presence, no statistical significance was found in the change in speed data, with p-values of 0.408 and 0.651 respectively.

Tests were performed on the relationship between select static evaluation responses

and the change in speed data. Statistical data of these responses is presented in Table 14.

Table 14: Statistical data of the change in speed for all scenarios depending on question response

Question	Response	Median Change in Speed (mph)	MAD
Have you seen a drone in flight near a roadway?	Yes	-0.265	1.28
	No	1.28	3.97
Should drones be allowed to be flown near roadways?	Yes	1.03	4.26
	No	0.478	2.24

The statistical significance of these differences in changes in speed due to the response to

both static evaluation questions are shown in Table 15 for each of the scenario types.

Table 15: P-values of the differences in the change in speed due to static evaluation responses from Wilcoxon pairwise test

Question	Pilots/Drone	Just Drone	All Scenarios with Either Drone or Pilots/Drone
Have you seen a drone in flight near a roadway?	**0.01**	0.181	**0.0066**
Should drones be allowed to be flown near roadways?	0.43	0.52	0.31

Statistical analysis between the average glance length and change in speed was

conducted for both scenario types, as well as between the percent of time variable data and

change in speed. Only one relationship was found to be statistically significant between the

change in speed data and the percent of time throughout the scoring window that a

participant viewed the drone in the drone only scenarios (p-value 0.00571). This

relationship is presented in Figure 15.

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Figure 15: Relationship between the percent of time observing drone in the drone only scnearios and change in speed

Finally, there were no significant differences in the change in speed between the scenario located in Latin Square no drone/pilots and the last presented scenario with no drone/pilots (p-value = 0.432).

4.4   Lateral Movement

The lateral movement difference data was calculated similarly to the change in speed data, as stated in section 3.6.1; specifically, the lane offset before the drone/pilot location was recorded and subtracted from the lane offset at the location of the pilot/drone. For this data, the Shapiro-Wilk test resulted in a statistically significant finding. Thus, the Wilcoxon test was used. The results are shown in Table 16.

Table 16: P-values of the differences in the change in lane offset with varying pilot presence roadside location from Wilcoxon test

Roadside Position of Drone/Pilot	Left	No Drone/Pilots
Left	-	0.180
Right	0.174	0.925

Given the lack of significance regarding the roadside position, lane offset was not further analyzed.

4.5 Visual Attention Results

Visual attention data was not normal according to the Shapiro-Wilk test. Thus, the Kruskal-Wallis and Wilcoxon tests were used to analyze this data, which utilize the median. The summary statistics represented in Table 17 and Table 18, reflect these values. In both tables, "percent of time glancing" represents the percent of time that a participant was observing the drone or drone/pilots during the analysis window, which began approximately 700 feet before the drone and/pilots in the scenarios and ended the moment the drone/pilots were no longer able to be seen through the forward windshield.

Table 17: Summary statistics of all scenarios with only drone present

Statistic	Median	MAD	Min	Max
Percent of time glancing	11.2%	10.5%	0%	43.4%
Average glance length (seconds)	0.43	0.32	0	1.62
Sum of all glances (seconds)	1.59	1.30	0	6.48
Total number of glances over 2 seconds	0	0	0	1

In Table 18, "both" represents the time that a participant was gazing at either the drone or pilot consecutively. This allows the representation of the total time that the drone and pilot were taking the gaze of the driver away from the roadway during one continuous time period, as participants may have switched from looking at the drone to directly looking at the pilots.

Table 18: Summary statistics of all scenarios with both drone and pilot present

Statistic	Location	Median	MAD	Min	Max
	Drone	7.6%	8.7%	0%	39.4%
Percent of time glancing	Pilots	13.3%	8.7%	0%	47.9%
	Both	*24.3%*	*14.1%*	*0%*	*55.7%*
	Drone	0.44	0.29	0	1.95
Average glance length (seconds)	Pilots	0.45	0.20	0	1.69
	Both	*0.58*	*0.26*	*0*	*1.99*
	Drone	1.11	1.37	0	5.64
Sum of all glances (seconds)	Pilots	2.07	1.36	0	8.87
	Both	*3.93*	*2.23*	*0*	*10.30*
	Drone	0	0	0	1
Total number of glances over 2 seconds	Pilots	0	0	0	2
	Both	*0*	*0*	*0*	*2*

The Kruskall-Wallis test revealed that many relationships between scenario variables and glance variables were not statistically significant, in both scenario types (with drone only and with pilots/drone). For all glance variables for both scenario types, there was no statistical significance found between gender, age, driving experience, drone height, static evaluation question "Have you seen a drone in flight near a roadway?" and "Should drones be allowed to be flown near roadways?".

In nine of the total 156 analyzed videos, drivers looked back at the drone/pilots in their rearview mirror after passing them. Five of those nine were of the pilots/drone scenarios, while the other four were drone only scenarios. Further, one participant made up three of those videos by checking in three of their scenario drives. Another participant checked in two of their scenario drives, with the final four occurring with other individual
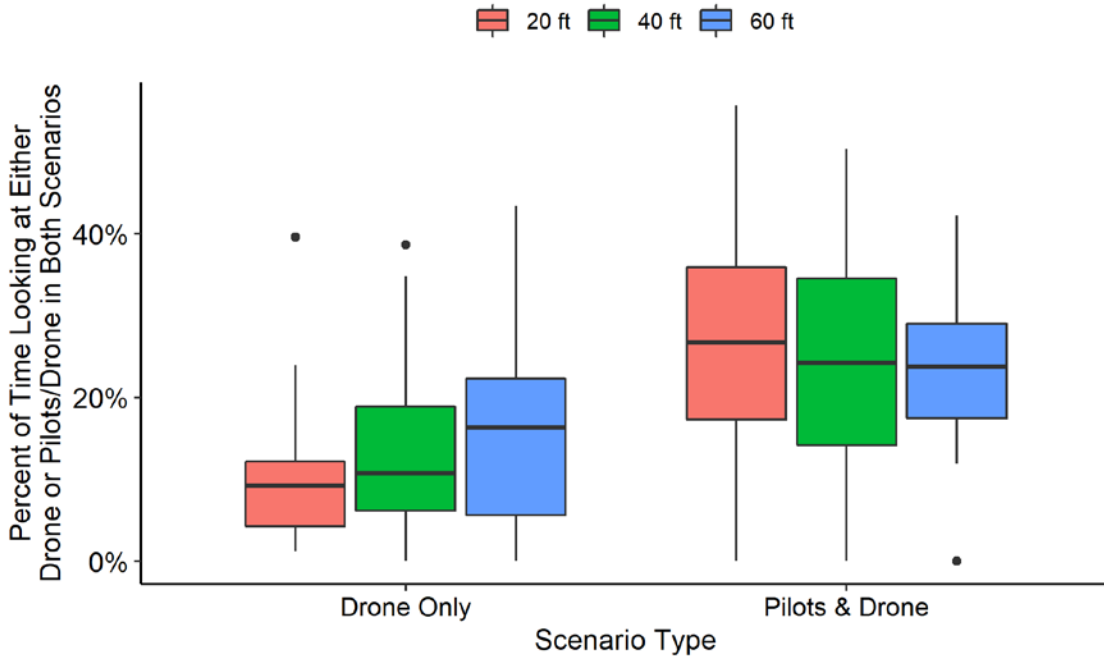
Figure 16: Percent of time observing either drone or pilot in both scenario types

participants. Additionally, in a total of 17 analyzed videos, the participant glanced at the drone or pilot for more than two seconds continuously.

There was found to be significant difference (p-value = 0.00) between the percent of time in the scoring window that a participant was looking at a drone in the "drone only" scenarios compared to looking at either the drone or pilots in the "pilots and drone" scenarios. This relationship is shown in Figure 16, with the addition of a split depending

on the drone height. It is noted that there were no significant findings comparing the drone heights with the visual attention data in either scenario type.

There was found to be a significant difference (p-value = 0.019) between the percent of time that participants looked at the drone in either scenarios. This is presented in Figure 17. This figure also breaks down this data, depending on the height of the drone; however, this variable was not significantly different within each scenario type.
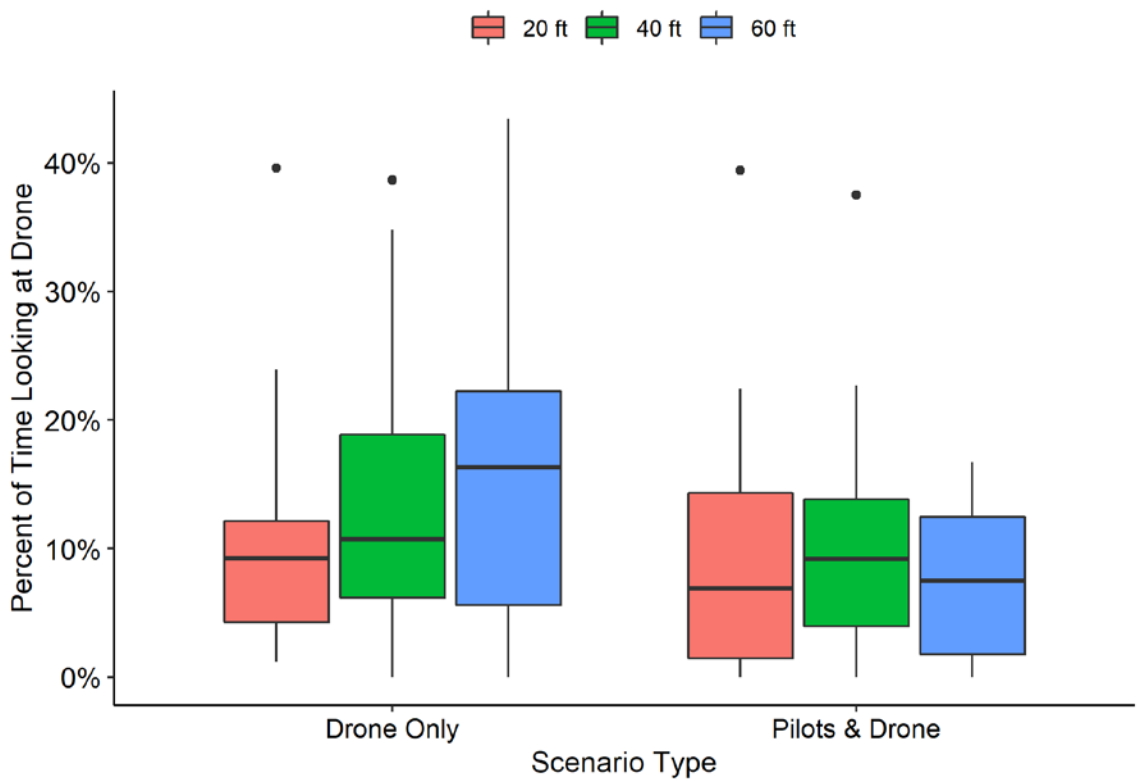
Figure 17: Percent of time observing drone in both scenario types
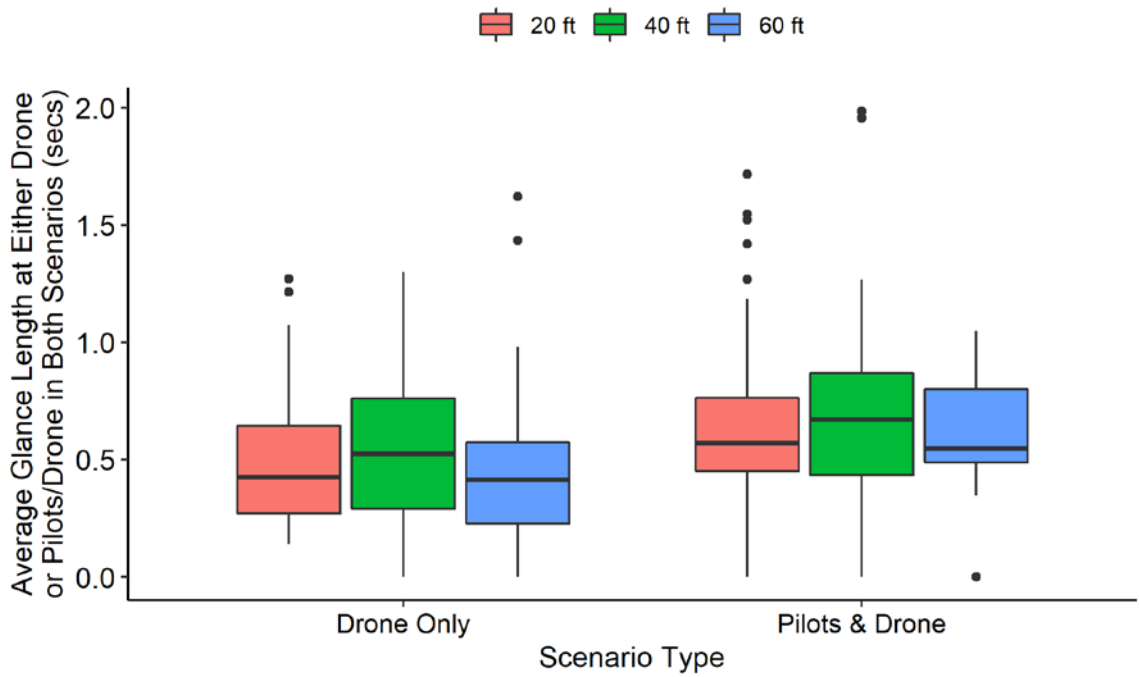
Figure 19: Average glance length observing either drone or pilots/drone in both scenarios types
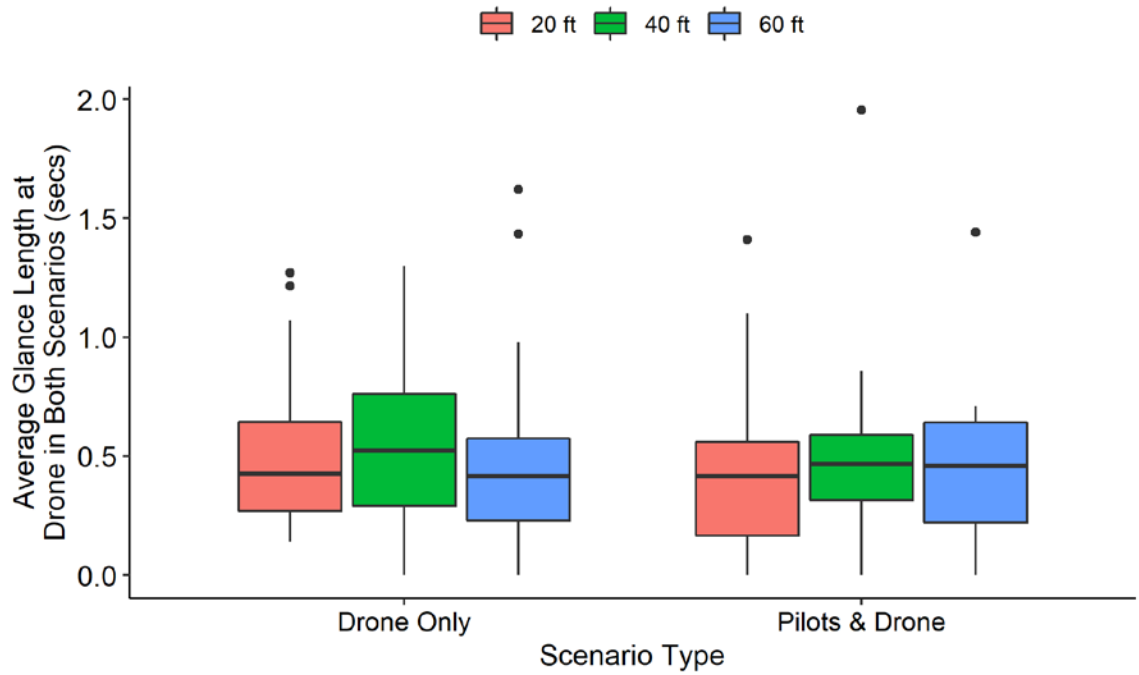
Figure 18: Average glance length observing drone in both scenarios types

The median average glance length at the pilots/drones in the pilots/drone scenarios

was 0.582 seconds (MAD = 0.264), while the median average glance length at the drones

in the drone only scenarios was 0.43 seconds (MAD = 0.316). This difference was found

to be significant. These results are displayed in Figure 19. Again, height of the drone was

not found to be significant. The average glance length observing the drone between both

scenario types, presented in Figure 18, was not found to be significant.

Analysis was completed between the speed and visual attention data. There were

no significant findings between the change in speed for all drone or pilots/drone scenarios

and the groups that looked at either the drone or pilot and those who did not look at all.

CHAPTER 5: DISCUSSION

This research investigated the potential for driver distraction due to UAS on the roadside through a literature review, driver simulator study, and static evaluation. The results of this research in the previous chapter are discussed in the following sections.

5.1 UAS Use in Transportation

As it was shown that the trend exists that UAS will continue to be utilized near transportation systems, it is vital that the possibility of distraction due to these systems is fully understood. With this information, informed decisions about policy in regards to where and how drones are flown in the vicinity of roadways can be made.

5.2 Static Evaluation

The answers to the short answers questions revealed many findings on how drones in the vicinity of roadways are viewed by drivers, as these responses were unprompted. Two of the responses to the first question, which did not state any information on drones/pilots, were pertaining to the drones the participants saw in the scenarios. Particularly, the response from one participant stood out as they stated that noticed they were looking for the drone even if it wasn't there. This observation from the participants shows that drones may be distracting in areas where they may be present, even when they are not present. The answers to the second question, which asked participants to write comments on the drones and/or pilots/operators from the simulator study, provided more detail and further insight into how drivers view these situations. In this question, participants were not asked about distraction; however, eight of the 28 participants noted that drones and/or their pilots could/were a distraction in the scenarios. Several other participants made note that the drones and/or pilots made them look away from the roadway. Several statements were also

made in regards to the location of the drone. While the drone was never placed over the roadway, it appeared to many participants that this was the case. Given that the drones were at fairly higher heights than the pilots heights in the scenarios, this is reasonable from a driver's perspective. However, it further adds to the argument that if drones are flown in the vicinity of roadways, it can appear that they are over the roadway to drivers; so even when drivers are not technically in harm's way due to a drone, it can appear that way to drivers. Thus, they may react negatively through their driving performance, creating potential hazardous situations in the real world. Finally, four participants stated that they kept looking for the drone or pilot when only one appeared to be present. This is dangerous, given that drivers would taking their eyes off of the forward roadway. Generally, many of these responses indicated that drivers would feel unsafe driving in these situations in real life.

Given that all but one participant of the study had seen a drone before, this question was unable to be statistically tested with the other independent variables of change in speed, change in lateral position, and visual attention. However, this does provide further insight into how popular drones are becoming in the United States. Of those 27 who had seen a drone, eight participants, or approximately 30%, had seen a drone in flight near a roadway. This value was higher than expected, but provided further insight into the following question of when these participants saw the drone. Four participants had seen a drone while driving vehicle. This data proves further that drivers are noticing drones while on the roadway, even today. When asked that their initial thoughts were when they saw the drone, none of these participants stated that they "ignored the drone"; oppositely, all participants noted that they "wondered what it was doing/why it was there." One participant was

nervous that it might even hit their vehicle. These responses prove that drivers remember these situations and even spend time thinking about the drone, possibly extensively. Thus, distraction due to drones may not only be visual, but also cognitive. More types of distraction at once lead to a longer time to recover from a distraction, creating a longer period of potentially hazardous driving (*78*). While further research would need to be completed on this topic, the dual-distraction in these drone presence situations is possible.

The short answer question of where participants had seen a drone in flight varied. Many participants had seen a drone in flight in a park, with a few stating they had seen them in flight at large events. With the exception that these answers show that participants easily recalled the times they had seen a drone in flight, no answers provided further insight regarding the focus of this study.

Participants were fairly split on the final question of if drones should be allowed near roadways, with 12 participants (43%) stating "yes" and 16 participants (57%) stating "no." The short answer of their reasoning provided more insight into their responses. Many who believed that drones should be allowed to be flown near roadways thought so as long as the pilot was responsible. Many more believed that the drone was just as distracting as other aircrafts. A few others noted that drones could collect data or help with first responders to crash locations. These responses indicate the possibility that some of these participants would believe that non-licensed pilots should not be able to fly near roadways. Those who believe that drones should not be able to be flown near roadways believed so mostly due to the possibility of them being a distraction to drivers, with several noting that this distraction could lead to crashes. Several of these participants believed that inexperienced operators flying near roadways could lead to dangerous situations. Overall,

these answers indicate that participants believed that overall, more experienced, responsible pilots are bettered suited for flying drones in the vicinity of roadways. However, overall, most believed that drones should not be flown near roadways due to the distraction possibility.

The static evaluation short answer responses provided a large amount of insight into how strongly the general public views this topic of drones and distraction. Generally, answers to these questions indicated many had straightforward opinions and did not require more information to discuss the possibility of drones being a distraction to drivers.

5.3   Change in Speed

The change in speed data was not normally distributed due to extreme cases of change in speeds. This was accounted for in the analyses through the use of specific significance tests which did not require normality. The change in speed from before the drone placement to the drone was low at less than one mile per hour at the median. The statistical significance in the change in speed between the age groups of 18 to 24 years old and 46 to 75 years old may be due to younger drivers being less cautious than older drivers. Younger drivers, specifically teens, are more likely than adults to make a critical decision error in some non-intersection locations, such as travelling too fast for conditions (*79*). This reasoning may also be the reason for the significance in the change in speed with the 10 years or more driving experience group compared to the two other groups.

The lack of statistical significance in the change in speed due to drone height or pilot presence aligns with research completed by Bowden et al. which found that average speed during distractions only reduced in situations that included a manual component (*78*).

The statistical significance in the change in speed due to the response of the question "*Have you seen a drone in flight near a roadway?*" indicates that those who have seen a drone near a roadway in real life may be more cautious than those who had not, as those participants had a high negative change in speed. Thus, this significance indicates that drivers who are more informed/understanding of drones may be more cautious in their approach to them. Additionally, the lack of significance in change in speed due to the response of the question "*Should drones be allowed to be flown near roadways?*" indicates that drivers' opinions of drones is not correlated to their driver performance in terms of speed.

The lack of multiple correlations between visual attention and change in speed data again aligns with previous findings by Bowden et al. that visual distraction alone is not enough change an average speed (*78*).

Finally, the lack of significance in the change in speed for the no drone/pilots scenario within the Latin Square design and the last scenario indicate that drivers do not change their driving performance in terms of speed after their exposure to scenarios with drones and pilots.

5.4   Change in Lateral Position

No significant results were found in the analysis of change in lane offset between all left, right, and no drone/pilot scenarios. Hurwitz et al. found that some drone encounters resulted in at least a portion of the participant's vehicle crossing into another lane; however, statistical analyses were unable to be completed due to the roadway geometry effecting driver positioning (*2*). The reasoning behind the lack of change in lane offset in the locations of the drone may be due to lack of drone movement and/or the inclusion of two

scripted vehicles in the opposing lane. Drivers are likely less comfortable drifting into another lane to avoid a potential hazard if there is a possibility of an oncoming vehicle in the adjacent lane.

5.5   Visual Attention

Visual attention data was not normally distributed, as data was close to zero, the natural limit of the data. Thus, the statistical tests used to analyze this data was selected to work with non-normal data. The lack of significance between all of the glance variables and scenario variables proves that no matter the background, age, gender, perspective on drones, etc., drivers are just as likely to be visually distracted, to the same degree, in scenarios with drones in the vicinity of the roadway.

In a small number of analyzed scenarios (9 out of 156), drivers looked back at the drone/pilots using the rearview mirror after passing them. This visual attention did not count towards the percent of time viewing the drone/pilots, as they could not be distinguished. However, this result further presents the potential cognitive distraction that drones present, as some drivers are still interested in viewing the drone/pilots even after they have passed them.

In 17 scenarios out of the 156 analyzed videos, drivers looked at the drone or pilot continuously at least once for more than two seconds. This is an important finding as eye glances away from the forward roadway two seconds or greater in length double the risk of a crash or near crash (*19*).

There was a significant difference in the percent of time during the scoring window that a participant was looking at the drone or pilots between the two scenario types, which was expected as the pilots/drones scenarios had more possible distractors than just the

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drone scenarios. Further, there was a significant difference in the percent of time that a participant was looking at just the drone between the two scenario types. This result presented that the drones were more visually distracting in the drone only scenarios than the pilots/drone scenarios. Thus, given these two findings, pilots are a leading factor in the distraction in the pilots/drone scenarios.

Average glance length, or dwell duration, of the drone in the drone only scenarios and of the pilots/drone in the pilots/drone scenarios was significantly different. The median glance length of 0.582 seconds in the pilots/drone scenarios show that drivers are not just glancing briefly, but rather spending the time to understand what the object is and what is it doing. With multiple glances at the drone and/or pilots, this can be problematic over a stretch of roadway.

Statistical analyses between visual attention and drone height proved the relationship to be insignificant. This shows that at any drone height between 20 feet and 60 feet next to the roadway, drones are equally distracting.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This research investigated the potential for driver distraction due to UAS on the roadside through a literature review, driver simulator study, and static evaluation. The results and discussion in the previous chapters allowed for conclusions and recommendations to be made, which are presented in the following section.

6.1   UAS Use in Transportation

A large number of users fly UAS in the United States, and it can be concluded that it is the trend that this number will continue to increase. With this increase, both commercially and recreationally, inside the transportation industry and outside, it is recommended policy reflect the hazardous scenarios that these systems pose when flown near roadways. These policies, informed by research such as this study and weighted with the data that UAS can collect for transportation studies, could lead to safer roadway environments, now and in the future.

6.2   Static Evaluation

The static evaluation revealed many insights of perspectives of drones in the vicinity of roadways. The following conclusions can be drawn from this evaluation:

- Several participants stated that the drones and pilots in the scenarios were or could be distracting.

- While a drone may not be directly over the roadway, it may appear to be that way given a driver's angle and the height of the drone.

- Of those who had seen a drone, 30% of participants had seen a drone in flight near a roadway, proving that drones are currently being flown near roadways in the United States.

- Participants who had seen a drone while driving remember these situations and spent time thinking about the drone while they were driving. Further, this proves that distraction due to drones may not be strictly visual, but also cognitive.

- There is an uneven consensus among participants whether drones should be allowed to be flown near roadways. However, there was general agreement on both sides of this answer that it would be better if the pilots of the drones were responsible and experienced pilots. Those who believed they should not be allowed to be flown near roadways believed so mostly due to the likelihood that they could be a distraction to drivers on the roadway.

From these conclusions, it is recommended that only licensed pilots be allowed to be flown in the vicinity roadways, if drones should be allowed to fly in the vicinity of roadways at all.

6.3   Change in Speed

Change in speed data was determined as the change in speed from 328 feet before the pilots/drone location to the pilots/drone location. From this data, the following conclusions can be made:

- Participants did not slow down their speed to a significant degree more at any drone height or due to pilot presence on the roadside.

- More participants slowed down in speed to a significant degree in their approach to pilots/drone on the roadside if they had previously seen a drone in flight near a roadway, compared to those who had not.

- Participants did not change their driving performance in terms of speed after their exposure to scenarios with drones and pilots in the same roadway environment.

Overall, these findings reveal that drivers generally do not change their speed while passing drones and/or pilots on the roadside.

6.4   Change in Lateral Position

Change in lateral position on the roadway while passing the drone/pilots in the scenarios did not prove to be a significant finding when comparing the situations of drones on the left and right, as well as situations where no drone was present.

6.5   Visual Attention

The visual attention data collected from the eye tracker provided insight into how visually distracting the drones and their pilots were to the participants. The following conclusions can be made from the results:

- Participants were just as likely to be visually distracted to the same degree due to the drone/pilots independent of their age, gender, years of driving experience, and perspective on drones and if they should be allowed to be flown near roadways.

- Drivers may be cognitively distracted by drones, as well as visually, as some drivers looked back at the drone/pilots in their rearview mirror after passing them.

- Drones and their pilots were critically distracting in nine out of the 156 analyzed scenarios as the participant observed them continuously for over two seconds at least once (*19*).

- Participants were just as likely to be visually distracted to the same degree at any drone height. Thus, drones at any height on the roadside between 20 feet and 60 feet are equally distracting.

- In scenarios when only a drone was present, the median percent of time in the scoring window that a participant spent viewing the drone was 10.5%, with a median average glance length of 0.43 seconds.

- In scenarios when both a drone and pilots were present, the median percent of time in the scoring window that a participant spent viewing either the drone or pilots was 24.3%, with the median average glance length of 0.58 seconds.

- Situations with both the drone and pilots present were more visually distracting than the drone only situations for participants.

Given the high amount of visual distraction due to drones and their pilots, it is recommended that policy be created to limit the situations in which drones are allowed to be flown in the vicinity of roadways.

6.6 Limitations and Future Work

A limitation of this study is the within-subject design, which cause potential fatigue effects. This can cause a participant to become bored or tired over the course of the scenarios. To limit this effect, the scenarios were incorporated with between-subject design features, limited in driver length to less than two minutes per scenario drive, and randomized in order using the Latin Square design. Another limitation of this study would be the selected drone heights, as they were only placed at three different heights. In reality, drones can be flown at heights between 0 feet and 400 feet. Finally, the overall younger age of the participants is a limitation, as the data represents a majority of younger drivers. Future work could future analyze drone heights to determine the height at which they become generally unnoticeable to drivers. Future work could also further analyze the cognitive distraction that drones pose to drivers.

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CHAPTER 8: APPENDIX A: TRADITIONAL COUNT DEVICES

8.6.1   Intrusive Devices

Currently, there are five types of intrusive speed collection devices that are common to use today: inductive loops, pneumatic tubes with automatic traffic recorders (ATRs), piezoelectric sensors, bending plates, and magnetic detectors (*31*). Each of these devices are analyzed in this section.

8.6.1.1 Inductive Loops

Inductive loops are wire loops that are installed in the pavement of a roadway to detect various traffic data, including speed data (*48*). However, to collect speed data, multiple detectors are often required. Typically, these devices are utilized to collect long-term traffic data at a location, as they need to be installed into the roadway using saws, causing disruption of traffic for installation and repair (*48*).

8.6.1.2 Pneumatic Tubes

Pneumatic road tubes with ATRs are rubber tubes that are placed across a roadway to detect vehicles through pressure changes that are produced as vehicles pass over the tubes. While they are accurate at collecting speed data (*80*), they require labor to be installed and uninstalled at specific locations on a roadway. This requires a temporary interruption of flowing traffic at many locations, depending on the time of installation and roadway volumes. During this installation and uninstallation, workers must cross the roadway, creating a safety hazard. In some circumstances, police are required to be present throughout this process to provide the safest environment for roadway users and the installation workers. This type of data collector differs from many of the other traditional

intrusive and nonintrusive devices, as they are not permanent and are meant to be placed at a specific location for only a short time.

8.6.1.3 Piezoelectric Sensors

Piezoelectric sensors gather traffic information, such as speed, by detecting the passing of a tire. Similarly to inductive loops, they also require traffic disruption for installation and repair, making them more useful for long-term data collection locations (*48*).

8.6.1.4 Bending Plates

Bending plate systems record the strain as a vehicle passes over it and calibrates to calculate vehicle speed and pavement and suspension dynamics. These systems are commonly used to collect data for weight enforcement purposes (*48*).

8.6.1.5 Magnetic Detectors

Magnetic detectors indicate the presence of a metallic object through the detection of perturbation in Earth's magnetic field. The installation of these detectors requires pavement to be cut or tunneling under the roadway, which, in turn, requires traffic interruption through a lane closure. They are typically unable to detect stopped vehicles (*48*).

8.6.2   Non-Intrusive Devices

Nonintrusive devices are typically systems that require minimal disruption and traffic to be installed and maintained as they are placed above ground, either overhead or on the side of the roadway. Types of these devices include microwave radar, laser radar, passive infrared, ultrasonic, and passive acoustic array (*48*, *81*).

8.6.2.1 Microwave Radar

Microwave radar devices utilize a radar sensor mounted over the middle of a lane or at the side of a roadway. These devices transmit a continuous wave Doppler waveform that can provide measurements of vehicle count and speed (*81*).

8.6.2.2 Laser Radar

Laser radar devices utilize a sensor that is typically mounted over a lane, which can provide vehicle data on volume, speed, length of the vehicle, and classification. Modern laser radar sensors can produce two- and three-dimensional imagery of vehicles (*81*).

8.6.2.3 Passive Infrared Sensors

Passive infrared sensors detect energy through two sources: (1) energy emitted from vehicles, road surfaces, and other objects in their field of view and (2) energy emitted by the atmosphere and reflected by vehicles, road surfaces, or other objects into the sensor aperture. These sensors can be mounted overhead of traffic or one the side of the roadway. Multiple detection zones of the sensor are needed for it to measure vehicle speed and length (*81*).

8.6.2.4 Ultrasonic Sensors

Ultrasonic sensors transit pressure waves to sound energy that are above the human audible range. These sensors can be placed adjacent to the roadway or mounted overhead. Ultrasonic sensors can measure speed when programmed or placed in a correct manner to do so (*81*).

8.6.2.5 Passive Acoustic Array Sensors

Passive acoustic array sensors detect acoustic energy or audible sounds produced by vehicles and are able to count vehicles and measure their speed. These devices can be

placed on the side of a roadway at specific angles and distances from the vehicles on the roadway to collect data accurately (*81*).

8.6.3 Off-Roadway Devices

Manual data collection equipment, such as radar guns, laser guns, and stopwatches, are still widely utilized for temporary data collection (*80*). In the Commonwealth of Massachusetts, these types of devices are most often utilized in the data collection process for the speed limit–setting process (*15*). Often, permanent data collection devices are not already at a location where the data needs to be collected, and installing a permanent device is unnecessary, given the short-term data need. In this section, laser guns, radar guns, and stopwatch manual counts are described.

8.6.4 Laser Gun

Laser guns, or LiDAR guns, use light detection and ranging technology which emit a series of infrared laser light pulses. When pointed toward a moving vehicle, this device is able to measure both the range and speed of the vehicle. This technology can be programmed to work in inclement weather and work through glass, though it does have a narrow field of view to report selected vehicles (*80*). When used according to correct guidelines, these devices are accurate within +1 mph to -2 mph (*82*).

8.6.5 Radar Gun

Radar guns can measure speed when pointed at a moving vehicle in the line-of-sight. These devices have a wide field of view and are programmed to report the fastest vehicle in its view (*80*). When used according to correct guidelines, these devices are accurate within +1 mph to -2 to -3 mph (*83*).

8.6.6 Stopwatch Manual Count

Manual counts, also known as running speed, are done using a stopwatch and two known start and stop locations. An observer starts and stops the stopwatch as a vehicle enters and departs the specified points marked in the section. The speed of the vehicle captured is then calculated dividing the distance between the two marked points by the time recorded (*80*). As humans have inconsistent and less accurate reaction times than automated devices, this type of count is rarely used for any type of engineering study.

Survey after Simulator (A.R.)

Survey Flow

Block: For researcher to complete prior to completion of survey. (19 Questions)
Standard: Block 1 (0 Questions)

Page Break

✳

Q1 Participant ID

_____

Q3 Thank you for agreeing to take this survey. While this survey is confidential, you will be asked to provide some non-identifiable demographic information. The responses collected from this survey will be reviewed and analyzed only by members of our research team.

Q2 If you agree to participant in our survey, please select the "I Agree" option before continuing:

○ I Agree (1)

Page Break

Q4 Age

  ○ 18 to 24 years old (1)

  ○ 25 to 45 years old (2)

  ○ 46 to 75 years old (3)

Q5 Gender

  ○ Male (1)

  ○ Female (2)

Q6 Driving Experience

  ○ Less than 5 years (1)

  ○ 5 to 9 years (2)

  ○ 10 years or more (3)

Q7 Do you usually wear eyeglasses/contacts when driving?

  ○ No, my vision without glasses or contacts is fine. (1)

  ○ Yes, I usually wear glasses while driving. (2)

  ○ Yes, I usually wear contacts while driving. (3)

  ○ Other (please specify) (4)

  _____

Page Break ───────────────────────────────────────

Q8 Please write any additional comments you may have on the simulator portion of the study you just completed in the text box below.

_____

Q9 Please write comments on the simulator portion of the study you just completed on the **drone, or Unmanned Aerial System (UAS)**, presented during some of the scenarios. Please also include any comments on the **pilots/operators** on the side of the roadway.

_____

Page Break

Q10

Q11 What are your thoughts on the use of drones?

_____

Q12 Have you ever seen a drone before?

○ Yes (1)

○ No (2)

Skip To: Q17 If Have you ever seen a drone before? = No

Page Break ───────────────────────────────

Q13 Have you ever seen a drone in flight near a roadway?

○ Yes (1)

○ No (2)

Page Break

Q14 When have you seen a drone in flight? (Choose all that apply)

☐ While driving a vehicle (1)

☐ While riding as a passenger in a vehicle (2)

☐ While riding a bicycle (3)

☐ While walking on a sidewalk or walking path (4)

☐ Other (please specify) (5)

_____

Skip To: Q16 If When have you seen a drone in flight? (Choose all that apply) != While driving a vehicle

Page Break ───────────────────────────────────────

Q15 What were your initial thoughts when you saw the drone in the sky while driving in the real world? (Choose all that apply)

☐ Wondered what it was doing/why it was there (1)

☐ Was nervous that it might hit your vehicle (2)

☐ Wondered who was flying the drone (3)

☐ Ignored the drone; didn't have any thoughts about it (4)

☐ Other (please specify) (5)

_____

Page Break

Q16 Where have you seen a drone in flight?

_____

Q17 Should drones be allowed to be flown near roadways?

○ Yes (1)

○ No (2)

Q18 Please comment on your reasoning.

_____

Page Break

Q19 **Thank you for participating in this study. Please let the researcher know you are finished taking the survey.**

CHAPTER 10: APPENDIX C: PARTICIPANT FORMS

ROADWAY SIMULATION STUDY
INFORMED CONSENT FORM

Principal Investigator: <u>Professor Michael Knodler</u>

Project Title: <u>Study of Roadway Variations</u>

1. **WHAT IS THIS FORM?**

   This is an Informed Consent Form. It will give you information about this study so you can make an informed decision about participating. You need to be 18 years of age or older to give informed *consent*.

2. **WHO IS ELIGIBLE TO PARTICIPATE?**

   Individuals who are between 18 and 75 years old and have had a regular driver's license for at least 18 months. Drivers who experience motion sickness, either in their own car as a passenger or driver, or in other modes of transport, should not participate. Drivers who have impaired vision that requires eyeglasses should not participant in the study.

3. **WHO IS SPONSORING THIS STUDY?**

   This study is sponsored by Safety Research Using Simulation (SAFER-SIM), which provides the funding to compensate participants.

4. **WHAT IS THE PURPOSE OF THE STUDY?**

   The purpose of this study is to evaluate the behavior of drivers going through various roadway configurations.

5. **WHERE WILL THE STUDY TAKE PLACE AND HOW LONG WILL IT LAST?**

   Participants will have one session which will last approximately 45-60 minutes and include questionnaires and simulator drives.

   The study session will take place at the Human Performance Laboratory (Elab Building, Room 110) located in the College of Engineering at the University of Massachusetts in Amherst.
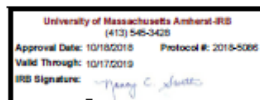
6. WHAT WILL I BE ASKED TO DO?

i) The experimenter will show you how to drive HPL's full car simulator (referred to as the "RTI simulator") in the Human Performance Laboratory (ELab, Room 110) and will give you general instructions for the drives. During the simulator drives, you should operate the controls of the simulator car just as you would those of any other car, and move through the simulated world accordingly. You should follow the speed limit and standard rules of the road and take care when braking.

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

iii) Once the eye tracker has been calibrated, you will then sit in the RTI simulator, and be given a practice drive to become used to the eye tracking device and the driving simulator. Once you feel comfortable in the RTI simulator, you will drive the simulator through a virtual course which will take about 15-25 minutes in total. If at any time during the drives you feel discomfort or motion sickness, you should ask the experimenter to stop the simulation.

iv) You will be asked to fill out one 5 to 7 minutes online survey which includes demographic and driving history, as well as your perspective of specified driving configurations after the experiment.

## 7. ARE THERE ANY RISKS OR BENEFITS ASSOCIATED WITH PARTICIPATION?

Participants may not directly benefit from participating in this study.

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

There is a small possibility for a breach of confidentiality, but the researchers will take every precaution to ensure that the data collected through the study remains confidential; refer to section 8 below.

It is possible that during the study period, due to the design of the simulation drives, some participants will feel themselves poorly maneuvered (hard braking, speeding, quick accelerations). Note that these kinds of errors are very common and that they are not unusual.

There are no known risks related to using the head-mounted eye tracking device.
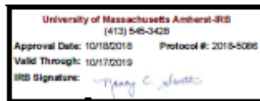
Note that driver performance of a participant in the laboratory has no impact on their actual driving abilities.

8. WHO WILL SEE THE RESULTS OF MY PERFORMANCE IN THE STUDY?

The results of this research may be published and submitted for presentation at professional society meetings and/or used by the approved researchers for internal purposes. No participant will be identifiable from the reports nor will any participant's name or initials be used in the reports. To maintain confidentiality of your records, the researchers will use subject codes, rather than names, to identify all data collected through the questionnaires and during your simulation drives. The data will be secured in the Human Performance Laboratory and will be only accessible by the principal investigator, Dr. Michael Knodler, and any other approved researchers for the study.

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

Data folders for this study will be kept in a locked file cabinet, with the informed consent forms kept in a separate locked file cabinet, within the Human Performance Lab. The lab itself has automatically locking doors that can only be opened with a key.

The cross-references for participants and their randomly generated coded ID numbers will be contained in a password-protected Microsoft Excel file stored on the lab's storage drive, which is not connected to the internet and is only accessible by lab personnel. Only lab personnel working as researchers on the study will be authorized to access the participant ID cross-reference file. All data files, participant questionnaires, and simulator and eye tracker videos for the study, except the cross-reference file will contain only the participants' randomly generated coded ID number and no identifying information.

For the online survey questionnaire specifically, the responses will be stored on SurveyMonkey and only be accessed through a secure network and password by the researchers only. SurveyMonkey has an extensive privacy policy and security statement.

9. WILL I RECEIVE ANY PAYMENT FOR TAKING PART IN THIS STUDY?

You will be paid $20 total as compensation for your participation in the study.

10. WHAT IF I HAVE A QUESTION?

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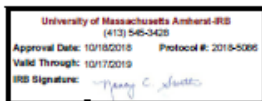
11. WHAT IF I REFUSE TO GIVE OR WITHDRAW MY PERMISSION?

Your participation is voluntary and that you may refuse to participate or may withdraw consent and discontinue participation in the study at any time without prejudice.

12. WHAT IF I AM INJURED?

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

13. SUBJECT STATEMENT OF VOLUNTARY CONSENT

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

_____   _____

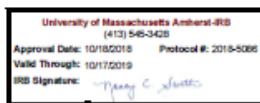Printed name and signature of participant   Date

14. EXPERIMENTER STATEMENT

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

_____   _____

Signature of person obtaining informed consent   Date

HUMAN PERFORMANCE LABORATORY

Participant Payment Voucher

=-=
**REMOVE THIS FORM FROM DATA FOLDER UPON
COMPLETION AND PLACE IN <u>CONFIDENTIAL</u> FILE**
=-=

I participated in the research project on driver performance.

_____ /_____ /_____
      (date)

For my participation in this study, I received a participation fee of $20.

_____
(Signature of participant)

_____
(Name of participant – please print)

_____
(Participant address: street, city, state, ZIP)

_____
(Signature of administrator)

Thank you for your participation in our study! Your participation is greatly appreciated.

Purpose of the Study:

We previously informed you that the purpose of the study to evaluate the behavior of drivers doing through various roadway configurations. However, more specifically, this study was put in place understand how drivers perceive flying Unmanned Aerial Systems (UAS) while operating a vehicle. The goal of our research is to quantify how UAS and/or their operators may be distracting to drivers various height conditions. It was hypothesized that the closer the UAS was to the roadway, the more distracting the device would be.

Confidentiality:

You may decide that you do not want your data used in this research. If you would like your data removed from the study and permanently deleted please contact Graduate Research Assistant, Alyssa Ryan at alyssaryan@umass.edu or speak to her in person in this lab, or in her office in Marston 34.

Whether you agree or do not agree to have your data used for this study, you will still receive $20 for your participation.

Please do not disclose research procedures and/or hypotheses to anyone who might participate in this study in the future as this could affect the results of the study.

Final Report:

If you would like to receive a copy of the final report of this study (or a summary of the findings) when it is completed, please feel free to contact us.

Useful Contact Information:

If you have any questions or concerns regarding this study, its purpose or procedures, or if you have a research-related problem, please feel free to contact the researcher, Alyssa Ryan at (315) 276-5045.

If you have any questions concerning your rights as a research subject, you may contact the University of Massachusetts Amherst Human Research Protection Office (HRPO) at (413) 545-3428 or humansubjects@ora.umass.edu.

If you feel upset after having completed the study or find that some questions or aspects of the study triggered distress, talking with a qualified clinician may help. If you feel you would like assistance please contact the Center for Counseling and Psychological Health (CCPH) at (413) 545-2337 (Mon-Fri from 8-5pm) - on weekends or after 5pm, call (413) 577-5000 and ask for the CCPH clinician on call. You can also contact the Psychological Services Center at 413-545-0041 (Monday-Friday 8am-5pm) or psc@psych.umass.edu.] In a serious emergency, remember that you can also call 911 for immediate assistance.]

Further Reading(s):

If you would like to learn more about distracted driving or UAS research please see the following references:

Hurwitz, D., M. Olsen, and Z. Barlow. Driving Distraction Due to Drones. 2018. Available at: https://www.oregon.gov/ODOT/Programs/ResearchDocuments/Driving_Distraction_due _to_Drones.pdf.

National Highway Traffic Safety Adminstriation - NHTSA. Distracted Driving 2016.Traffic Saf. Facts, 2018, pp. 1–8. Available at: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812517 [Accessed June 27, 2018].

Misokefalou, E., F. Papadimitriou, P. Kopelias, and N. Eliou. Evaluating Driver Distraction Factors in Urban Motorways. A Naturalistic Study Conducted in Attica Tollway, Greece.Transp. Res. Procedia, Vol. 15, 2016, pp. 771–782.

Barmpounakis, E. N., E. I. Vlahogianni, and J. C. Golias. Unmanned Aerial Aircraft Systems for transportation engineering: Current practice and future challenges.Int. J. Transp. Sci. Technol., Vol. 5, No. 3, 2016, pp. 111–122. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2046043016300533.

Kanistras, K., G. Martins, and M. J. Rutherford. A Survey of Unmanned Aerial Vehicles (UAVs) for Traffic Monitoring. 2013, pp. 221–234.

Please keep a copy of this form for your future reference. Once again, thank you for your participation in this study!

CHAPTER 11: APPENDIX D: STATIC EVALUATION QUESTIONS SHORT

ANSWERS

Please write any additional comments you may have on the simulator portion of the study you just completed in the text box below.

- *it could have more realistic turning*

- *Hard to gauge how fast your going besides consistently looking at speedometer*

- *Not good for tall people*

- *great use of drones!*

- *Glasses were a little tight and i felt them slip a tiny bit idk if that messes up the data*

- *nice new car!!!*

- *The weight of the steering wheel was very good, it felt a lot like a real car.*

- *Noticed that I was looking for the drone which was present in some tests even if it wasn't there*

Please write comments on the simulator portion of the study you just completed on the drone, or Unmanned Aerial System (UAS), presented during some of the scenarios. Please also include any comments on the pilots/operators on the side of the roadway.

- *Drones were more easy to spot when pilots were there.*

- *4 blade drone, black color, first few simulations there were two people operating the drone in view, a father and son it appeared*

- *I didn't find the drones very distracting till they were placed at the intersection with the drone flying low.*

- *The drones in the simulator were more distracting when there wasn't a pilot/operator nearby because I expected there to be one. Also the drones seemed less realistic because they were so stationary (not sure if that made them more or less distracting).*

- *Changed positions slightly sometimes... other than that yup they were there*

- *They were distracting when they were right next to the road, otherwise they seemed fine.*

- *If this was in real life, I would have been very distracted and disturbed to see a drone above the road, especially with seemingly unprofessional operators.*

- *Distracting and would have been worse on a busier road*

- *I noticed the drones in the different scenarios and i definitely took my eyes off the road to look, but i did not find them too distracting.*

- *very stable flight, good pilots*

- *Drone was in most of the scenarios. Operators were present in ~3/4 of them. Sometimes it was two looking at it, sometimes one operating, sometimes it was on its own*

- *drone caught my eye more than the pilots*

- *It was unusual to see a drone overhead while driving. I was watching for the operators of the drone and was unable to locate in some of the simulations.*

- *I remember the drone was sort of a symmetrical rectangular shape with two fins. I think I may have remembered an operator only once wearing a brown coat*

- *I saw them, and wondered if the drone was a 'simulator software artifact" vs an intended drone. i saw the person by the side of the road and saw that he disappeared in later scenarios*

- *I usually noticed the drone first and then once I noticed the drone my eyes searched for people that were operating it.*

- *the drone and the operators were distracting*

- *Interesting.*

- *I noticed the drones and the operators but I don't think they really affected my driving besides looking away from the road.*

- *The system is pretty well done, it feels like I'm actually test driving the car for something*

- *It felt odd when I was turning. I am so used to seeing actual things in my rear view mirror while driving, so that did not feel natural.*

- *did not notice the drone, noticed the two operators on the left side of the intersection then saw them moved to the right side of the intersection*

- *At first, i could not tell what the drone was until i was closer to it. Sometimes there were 2 guys standing below the drone, looking at the controller of the drone. I believe they were standing on the left side one or two times*

- *I noticed that they very often caught my eye and made me look away to see what exactly they were.*

- *As noted before, I kept looking for the drone even if it wasn't present in the current scenario. Having the operators nearby made it easier to spot the drone, but added*

a second distraction. The operators were also situated close to the road and in important areas (near intersection signage) which was not ideal.

- *I consistently noticed it after the second time I saw it. It first, I thought it was a screen artifact but then I realized that it was a drone. When I first saw the people, I only noticed that it was people and not what they were doing. The drone was on the side of the road and in one of the simulations, the drone was directly over a 4 way intersection. I noticed that when the drone was present I always looked at it and almost tracked it. My speed was faster than that of the posted 35mph speed limit.*

- *The drones were definitely a distraction to my driving in the study, I couldn't help but look up at them as they were passing by.*

What are your thoughts on the use of drones?

- *Drones may cause distractions for drivers.*

- *they have many potential benefits but their effect on privacy could be detrimental*

- *I think that drones are a great tool that can be used to safely collect imagery data that would other wise be unsafe and costly but should only be operated for these purposes by licensed drone pilots who think of safety of both the aircraft and people near the flight path of the aircraft*

- *I think they can be fun and some of them take really cool pictures/videos but I also understand the dangers of them and think there should be more regulations about where/when they can be flown.*

- *useful.. maybe creepy, but useful*

- *Great tools, I worry about their impact on wildlife*

- *I think it's interesting and can be a fun hobby. But, recreational users should use them in a large field.*

- *They're cool but lately have been getting in the way at national airports*

- *they can be distracting if they are super close to your car*

- *good tech but will soon need regulation*

- *They are cool*

- *Don't really have much against them. Not a fan of military ones bombing people but they can get interesting footage and pictures*

- *a bit of a distraction on the road but will probably become more common*

- *I thought it was interesting to see a drone fly by.*

- *I think they are beneficial, not only in terms of cinematography and photography, but with delivering cargo and stuff*

- *useful tools*

- *They seem practical for a lot of industries, and enjoyable for recreation.*

- *fun for kids if done safely*

- *Interesting and useful technology. Their use should be regulated however for safety and privacy issues.*

- *I think they can be useful for certain purposes, like photography, but can be distracting or a nuisance for other reasons.*

- *They make you look for sure*

- *There are pros and cons to them. The major cons are safety of wildlife and privacy of others.*

- *Depends on the purpose, i would be pretty annoyed if they become a common site outside while driving around or walking outside*

- *I think that they are a cool way of looking from a bird's eye view but can get in the way in terms of driving and overall security*

- *I think they offer a lot of entertainment and practical purpose, and have never really encountered any issues with them.*

- *They are cool and can be useful/fun, but their usage should be regulated more universally and operators should be trained to some extent, especially when operating in populated/highly traveled areas.*

- *I own a phantom 4 professional and fly it to caputre nature and for fun. I think they are not very mainstream at this time and are mostly used by consumers to capture some videos and pictures for fun. There are commercial applications of a drone ranging from fire fighting, electrical transport tower inspection thing.*

- *Drones are a cool way to take pictures and analyze from above*

Where have you seen a drone in flight?

- *ski mountain and in a park*

- *my house*

- *At parks/conservation land/forests*

- *In a large field/park*

- *My brothers wedding and at work*

- *beaches*

- *In different parks and fields*

- *demonstration at expo show*

- *At an outdoor event.*

- *yes*

- *At a park.*

- *parks*

- *At large events, like fireworks on 4th of July, or at my school for Video Production class*

- *At a wedding, the videographer used it to capture the day*

- *on a field or over a body of water*

- *Yes, at a park*

- *At a park, in a field or backyard, and at certain special event*

- *At a school during a commercial filming*

- *Music festivals, at the beach*

Please comment on your reasoning [as to why drones should/should not be allowed to be shown near roadways].

- Answer to previous question: No
  - *It can be distracting and may even cause accidents due to those distractions and/or inexperienced pilots.*
  - *They are just too distracting. As a driver, you never know who is operating the drone and what it will do next. I haven't seen one while driving, but I would be afraid of it hitting my car, therefore making me distracted from actually driving.*

o *I think professional photographers, mappers, etc, should be allowed to have larger use of drones. But, recreational drone users should not be allowed to use them near a roadway. This is because they are inexperienced operating the device, and could crash into the road and that the drone may be poorly made and can fail, and also crash into the road. I think this can be both distracting and dangerous to drivers.*

o *I think they are distracting and if an inexperienced pilot flies them over a car it could swerve and crash*

o *I think that drones should have to keep a certain distance from the road ways so that drivers do not get worried when they are close to the car*

o *They can potentially be distracting to drivers, and worst case- can fall and disrupt traffic*

o *drone and pilot distract driver attention and pilots may not be in proper location to avoid harm or have proper attention to auto traffic*

o *its dangerous because it can be a distraction*

o *It could be a driving distraction, and also dangerous if the operator doesn't know what they're doing.*

o *They are distracting while others are driving.*

o *I think drones over roadways can be distracting for drivers, especially those easily distracted while driving. They are also a safety concern if they malfunction or battery dies and they fall onto a moving vehicle*

o *Depending on what is going on, it could be distracting for any driver that might be staring at it to determine what it is.*

- o *After being in the driving simulator it would make sense to prohit drones from being near roadways because they do seem very distracting. There are plenty of places to fly a drone other than a roadway.*
- o *Drones can be a distraction (unless sufficiently high or far away from the road). There are also no insurance requirements for operators, so if a vehicle was struck by a drone getting the damage repaired by the drone operator could be a pain.*
- o *They are unpredictable and dangerous when not operated properly*
- o *They were very distracting, looking up at the drones took my vision far from the road where it should have been.*
- Answer to previous question: Yes
  - o *to some degree they should be allowed near roadways, just as long as they aren't flown as low as freight trucks*
  - o *I believe that drones should be only be flown near roadways by licensed pilots who are trained because i believe that drones can be used to collect all sorts of data from real time driving data to imagery data.*
  - o *efficiency of airspace*
  - o *They can be used to gather info to make our roads better, and maybe they could be used to help first responders to accidents*
  - o *hard to completely avoid flying over roads. maybe just limit hovering over highways*

- *I did not find the drone too distracting so as long as the pilot/operators stay clear of the roadway and are able to keep the drone under control I see no harm in operating them near a roadway.*
- *It was as distracting as an airplane passing overhead*
- *they are distracting, but really not more than helicopters, planes, other flying objects, and ground based activities. it would be another law that would probably be time consuming/ difficult to enforce*
- *I don't see any problems with them being flown near roads if the operator is responsible and keeps it high enough.*
- *They can be distracting to drivers, but so can anything else in the sky like planes, birds, etc. I don't think they should be allowed to fly very close to cars.*
- *Why shouldn't they? There are planes an other aircrafts that fly near roadways too*