DRIVING DISTRACTION DUE TO DRONES

Final Report

AGREEMENT #31167 - PROJECT 3

RESEARCH

Oregon Department of Transportation

DRIVING DISTRACTION DUE TO DRONES
FINAL REPORT

AGREEMENT #31167 - PROJECT 3

by

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16. Abstract

Drones are an emerging technology with various potential commercial and recreational uses. Based on the current literature and existing regulations related to drone operations, there are gaps in knowledge related to the potential safety concerns of drone operations near roadway infrastructures. A randomized, partially counterbalanced factorial experimental design was used to evaluate the effects of three independent variables – lateral offset, flight path, and land use – on driver distraction due to drone operations near the roadway. A total of 54 participants initiated the simulator study, 24% of whom experienced simulator sickness, resulting in a usable sample of 39 participants (17 women and 24 men). Study findings from the total fixation and dwell durations showed that the frequency and length of glances at drone operations increased the closer the drone operation was to the roadway. Drone operations seemed to be more distracting in rural environments. Finally, there was a potential for unsafe glances (dwell duration > 2 seconds) at all three lateral offsets: 0 ft, 25 ft, and 50 ft, although the greatest frequency occurred at the 0-ft offset.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	ml
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
m^2	meters squared	1.196	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

1.1 RESEARCH OBJECTIVES

The purpose of this research is to determine the distance from the edge of roadway at which drone operation around highway corridors will potentially become a visual or cognitive distraction, degrading driving performance. The primary hypothesis is that the potential for distraction increases with proximity of the drone or operator to the roadway. The study also investigates the potential for distraction due to drones across the functional classification of roadways and the density of development adjacent to the roadway. A secondary hypothesis is that the optimal encroachment avoidance zones may differ between urban and rural areas.

To meet the research objectives, a detailed study was performed in Oregon State University's (OSU's) Driving Simulator Laboratory. The driving simulator includes a full-size 2009 Ford Fusion cab, a motion base, three liquid crystal on silicon projectors, and a digital light processing projector. A mobile eye-tracking system was used to measure the visual attention of participants.

1.2 BENEFITS

It is anticipated that this research project will provide necessary empirical information to support development of Oregon Administrative Rules or Statutes regulating drone use in highway airspace. The resulting information could be used internally by the Oregon Department of Transportation (ODOT) in establishing safety protocols and best practices in its own drone operations, which have increased substantially in recent years. Finally, this information could benefit other state Departments of Transportation (DOTs) in developing similar statutes or rules.

1.3 TERMINOLOGY

Advances in drone technology have led to the rapid development of a new industry and specific terminology (lexicon) to communicate a common understanding across the topic. However, because interest in drones has dramatically increased in recent years, and the terminology varies across fields, there is the potential for confusion in communication. To address this issue, Table 1.1 provides standard definitions for the terms "drone," "unmanned/unoccupied aerial system (UAS)," "small unmanned/unoccupied aerial system (sUAS)," "unmanned/ unoccupied aerial vehicle (UAV)", "hobby/recreational drone," and "non-hobby/commercial drone."

Two definitions are provided for the term "drone." The first definition is a generic one that will be used throughout this report. The second definition, set by the FAA, is the standard definition of drone in the industry. The FAA uses the terms "UAS" and "drone" interchangeably. For consistency of understanding, this report will use a generic definition for "drone," regardless of what term is used in the reference source. Other terms may be used periodically in the literature review when a different term than "drone" is more appropriate.

Table 1.1: Definitions of Drone Terminology (FAA 2012)

TERM	DEFINITION
Drone	Report Definition: Unmanned aircraft, operated remotely by a pilot on the ground, that qualifies under the FAA's definition of a sUAS and can be used for commercial or recreational purposes
Drone/UAS	FAA Definition: Unmanned aircraft and associated elements (including communication links and components that control the unmanned aircraft) that are required for the pilot to operate safely and efficiently in the national airspace system
sUAS	Specific subset of UAS in which the aircraft weighs >0.55 and <55 lb
UAV	Aircraft operated without the possibility of direct human intervention from within or on the aircraft
Hobby/Recreational Drone	Any drone use by an individual exclusively for the enjoyment of the operator and not for any official purpose
Non-hobby/Commercial Drone	Any drone use that is not for a hobby or recreational purpose. These uses include government, research, and business purposes

1.4 ORGANIZATION OF THE REPORT

This report is organized as follows. Chapter 2 provides a literature review of key information regarding drones and driver distraction. This section includes background on the characteristics and uses of drones, including in transportation, a review of federal and state legislation related to drones, and a discussion of driver distraction as a safety issue. Chapter 2 concludes with the specific research questions that were addressed with this project. Chapter 3 presents the methodology, including the design and implementation of the study and participant testing in a high-fidelity driving simulator. Chapter 4 describes the analysis techniques and results of the driving simulator study and analysis. Chapter 5 discusses the results. Chapter 6 summarizes the principal findings of the work and provides recommendations for ODOT. Chapter 7 is a collection of the references of the work cited in this report. Appendices provide supplementary documentation for the material presented in this report.

2.0 LITERATURE REVIEW

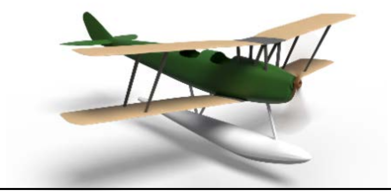
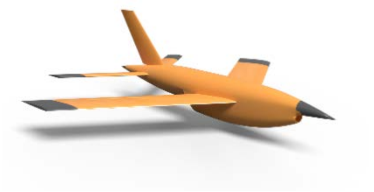
This chapter documents key information regarding drones and driver distraction. Government policies, guidance documents, and published literature were reviewed with a focus on types and uses of drones, existing regulations, and driver distraction. This literature review examines five topics related to driver distraction due to drones, including:

- Background of drone use and overview of driver distraction due to drones
- Characteristics of drones, including types of drones and system components
- Uses for drones in transportation and other industries
- Review of existing federal and state regulations due to drones, and
- Driver distraction as a safety issue and use of driving simulation to measure distracted driving

2.1 BACKGROUND

Unmanned flying vehicles have been conceived of and implemented for more a century (Table 2.1), primarily for military purposes (surveillance or attacking). Recent technological advances have made drones smaller, more affordable, and more available, creating demand for drones among individual hobbyists and commercial or public entities. This report focuses on hobby and commercial drones, which are in the public spotlight due to their increasing use.

Table 2.1: History of Military Drone Use (Pure Funds 2017, Images Courtesy: Corey Barlow)

YEAR OF INTRODUCTION	TYPE OF USE	EXAMPLE	GRAPHIC
1918	Flying bomb	Kettering Bug	
1935	Target practice	DH-82B Queen Bee	
1964	Surveillance	Lightning Bug 147SC	
2001	Hunter-predator	MQ-9 Reaper	

Drones operate in Class G airspace (<700 to 1200 ft above ground level) of the National Airspace System (NAS). As such, their use can be regulated by the FAA (FAA undated). The FAA is committed to promoting growth of the drone industry while maintaining safety. In 2015, the FAA began requiring drones to be registered and marked (discussed further in Section 2.4.1 Federal Regulations). As of March 2016, more than 400,000 drones had been registered with the FAA's online system (FAA 2016a). This number is expected to increase rapidly over the next 5 years (Table 2.2, Figure 2.1).

Table 2.2: FAA Annual Drone Sales Projections by Year, In Millions (FAA 2016a)

TYPE	2016	2017	2018	2019	2020
Hobby drones	1.9	2.3	2.9	3.5	4.3
Commercial drones	0.6	2.5	2.6	2.6	2.7

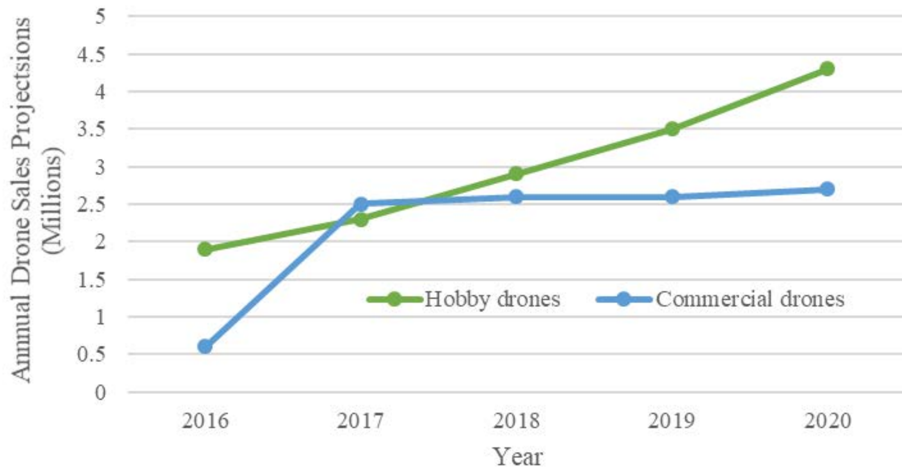


Figure 2.1: FAA annual drone sales projections by year, in millions

Although drone use has many associated advantages and economic opportunities, the rapid growth of the drone industry could be problematic. One safety issue is the potential for hobby or commercial drones to become distractions for drivers when flown near roadway infrastructure. This issue has seen little attention to date. A 2015 publication from the UAS Legislative Task Force of the 29th State Legislature in Alaska recognized the potential for drones to cause distractions to drivers. This document, which primarily discusses privacy concerns related to drones (UAS Legislative Task Force 2015), lists several FAQs and answers about drone use in Alaska. For example, the following question posed in this document relates to driver distraction:

"I understand why it's not safe to fly a drone near heavy traffic but what about privacy?"

The document provides the following three responses to this question, aimed at a general audience, drone operators, and private citizens, respectively (UAS Legislative Task Force 2015):

- "General: A drone flying near traffic could distract drivers and create unsafe driving conditions, including accidents. Drivers should keep their eyes on the road, and drone operators should keep their UAS away from traffic.
- Drone Operator: Flying over roads can cause distraction and potential automobile accidents on a road system. Don't fly your drone near high traffic roadways.
- Private Citizen: Not only are drones dangerous over busy traffic but most drivers don't want to be GPS tracked or photographed. If you see one, keep your eyes on the road. Pull over to report it to local law enforcement if you think its creating unsafe conditions or collecting data inappropriately."

The document contains the cartoon in Figure 2.2 to illustrate this concern.

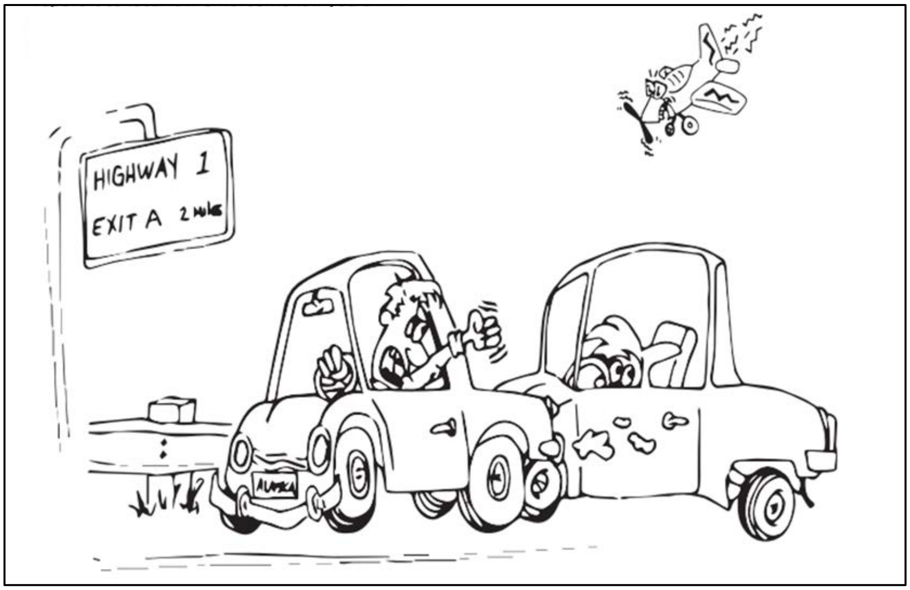


Figure 2.2: Cartoon on driver distraction to due to drones (UAS Legislative Task Force 2015)

While identifying driver distraction caused by drones as a potential issue, this publication highlights a lack of information regarding how and where drivers are distracted by drones. The answer provided for the drone operator provides few specifics. There is no guidance for how far from a high-traffic roadway the operator must be (i.e., the term "near" is not quantified). In addition, the answer acknowledges high-traffic roadways but does not consider implications for low-volume roads. It does, however, highlight that the distraction is primarily visible in nature.

The topic of driver distraction due to drones is fluid. Currently, drones are still a novelty. It is relatively rare to see a drone flying and even rarer to see one flying near a roadway. As such, the potential for distraction could be higher if drivers are curious or concerned about the drone flying in their field of vision. As drones become an important tool for more commercial and governmental entities, and as hobby usage increases (e.g., Table 2.2), drone use around critical infrastructures, such as highways, will likely continue to rise. In the short term, distraction caused by drones could be hazardous. Nevertheless, as the public adjusts to the increased use of drones, the novelty and concern may decrease, and this increased level of familiarity may impact the potential distraction caused by drones.

2.2 CHARACTERISTICS OF DRONES

Most early military drones closely resembled the aircraft of the time. Although many current civilian and military drones still use a fixed-wing airplane-style configuration, various drone types are commercially available today. The following sections describe the drone system components and types of drones that are currently available for hobbyists and commercial entities, including sUAS drones.

2.2.1 Drone System Components

All drone systems contain the same three basic components: vehicle/platform, payload, and ground control system. Although these components differ slightly based on drone type and intended use, there are fundamental similarities across drone systems. Descriptions of the three drone system components from the Unmanned Aerial Vehicle Systems Association (UAVSA) are included in Table 2.3. These components work together to allow the drone system to work safely and effectively. The payload, which allows the drone system to complete the desired task, can be changed based on the needs of the user, which allows flexibility of use.

Table 2.3: Components of Drone Systems (UAVSA 2017)

COMPONENT	DESCRIPTION
Vehicle/Platform	The vehicle component is comprised of the connection of the following elements: • Vehicle airframe • Propulsion system • Flight control system • Navigation system • Environment sensor system
Payload	The payload can be whatever is necessary for the drone to complete its desired task. The following are some example payloads: • Sensing systems and scanners • Infra-red systems • Radar • Dispensable loads (e.g., flares) • Environmental sensors (e.g., thermometer)
Ground control system	The drone pilot interfaces with the ground control system, which is generally set up as a single operator station. Elements of this station include the following: • Avionics flight display • Navigation system and display • System health and diagnostics display • Communications system • Data processing system

2.2.2 Types of Drones

For current commercial and hobby use, there are three primary types of drones: fixed-wing, helicopter, and multicopter. Fixed-wing drones resemble common aircraft in proportion and characteristics. Helicopter drones have a single point of rotation for the blades. Multicopter drones have smaller blades, typically configured in sets of four (quadopter), six (hexacopter), or eight (octocopter). Table 2.4 provides a graphical example of each type, while Table 2.5 describes some of the advantages and disadvantages of the three basic types of drones.

Table 2.4: Basic Types of Drones (Images Courtesy: Corey Barlow)

TYPE	FIXED-WING	HELICOPTER	MULTICOPTER
Graphic			

Table 2.5: Advantages and Disadvantages of Different Drone Types (Modified From Otero et al. 2015)

TYPE	ADVANTAGES	DISADVANTAGES
Fixed-wing	• Capable of higher speeds • Can carry heavier payload than multicopter • Longer flight time/distance	• Cannot take off or land vertically • Low maneuverability
Helicopter	• Can carry heavier payload than multicopter • Vertical takeoff • Can hover in place	• Low maneuverability • Low transverse speed • Requires constant user input
Multicopter	• High maneuverability • Adaptable to various uses • Vertical takeoff • Can hover in place	• Low transverse speed • Moderate payload capacity

Selection of a type of drone will depend on the intended use. For some uses, one particular drone type will be preferred over another. Pilot comfort and experience are additional factors to be considered in the selection of drone type for a particular task.

2.3 USES FOR DRONES

Historically, drone use was limited to military applications. With the influx of commercial and hobby drones, the potential uses for drones have and continue to grow in every sector.

2.3.1 Current Uses in Transportation

State DOTs in the United States are exploring the possibility of using drones to aid in the construction and maintenance of roadway infrastructures. For example, a March 2016 report from the AASHTO based on a survey of state DOTs contained two primary sections focused on how state DOTs are currently using drone technology and the potential benefits from those uses. Seventeen states have researched or used drones to complete tasks, such as inspections of bridges and areas at high risk of flooding, rockslides, or landslides (AASHTO 2016). Another 16 state DOTs were assisting with drone policy or research. Figure 2.3 maps these results.

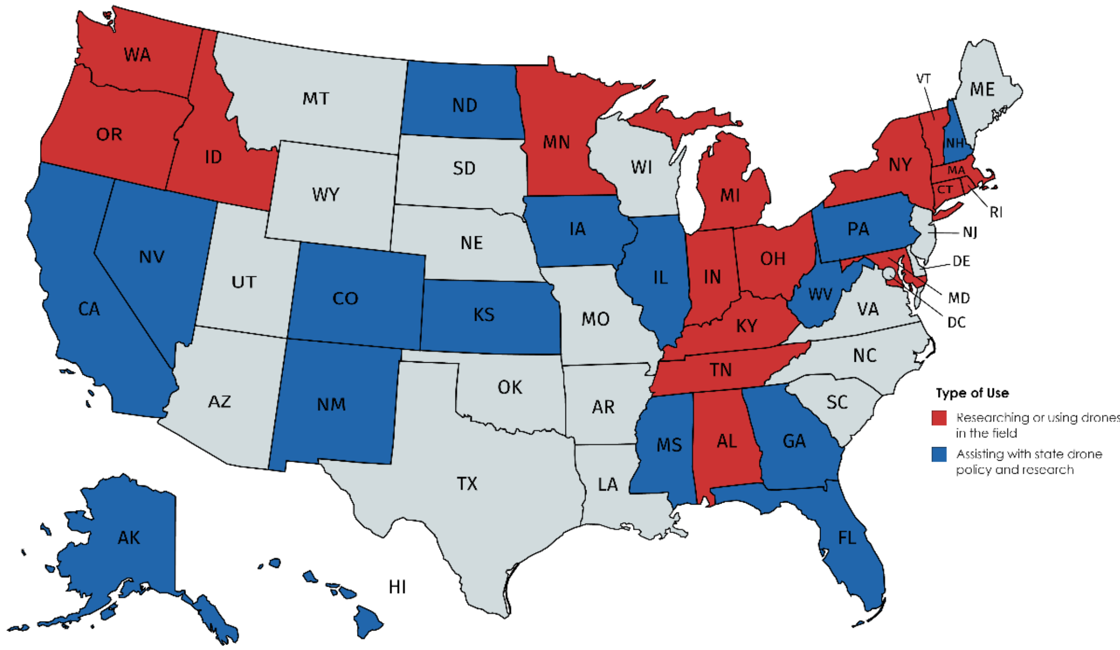


Figure 2.3: States DOTs working with drones (data from Giannekas 2017)

The report highlighted four specific benefits of drone use, particularly when collecting data (AASHTO 2016):

- **Improved Safety:** Drones provide a mechanism for state DOTs to keep workers away from high-risk environments.
- **Time Savings:** Set-up time for tasks with drones can be considerably shorter, leading to quicker turnarounds on field tasks.
- **Cost Savings:** Only two people are needed to conduct a drone operation; thus, the costs of manual labor for tasks such as bridge inspections are drastically reduced.
- **Reduced Congestion:** Drones can potentially be used to conduct bridge inspections without (or with minimal) traffic disruptions, thus markedly reducing user delays.

A recent FHWA report (Mallela et al. 2017) discusses the diverse range of transportation applications for drones throughout the country (summarized in Table 2.6) and evaluates the return on investment of utilizing drones. Potential savings make the use of drones enticing to state DOTs. Drone use and research among state DOTs are expected to continue to increase, especially as drone technology improves.

Table 2.6: Applications of Drones in Transportation (From Mallela et al. 2017)

APPLICATION	EXAMPLE APPLICATIONS
Traffic monitoring and surveillance	Video collected from a camera on a UAS can be used for traffic surveillance, identifying traffic congestion, and counting traffic
Structural inspection	Sensors on a gimbal (e.g., RGB and thermal cameras) can be flown along structures for collecting high-resolution, close-up digital imagery and video; enables remote, visual identifications of defects
Construction safety inspection and security	Safety managers at construction sites can use real-time video for quickly assessing current conditions, both visually and audibly
Roadside condition inventorying, assessment, and inspection	High-resolution aerial images and video can be used to assess the condition of roadway assets, determine the roadway's level of service, and set maintenance priorities
Topographic surveying and mapping	Overlapping aerial images from a UAS can be mosaicked and converted into orthophotos and 3D point clouds by SfM algorithms; some UAS can also lift small lidar systems for surveying and mapping
Monitoring construction progress and status	Aerial images collected from repeated flights can be used to monitor and document construction progress; images can be used to detect changes to areas neighboring a construction site
Estimating earthwork volumes	Digital surface models (DSMs) can be constructed from overlapping aerial images or lidar; volumes of stockpiles, earthwork, or complex objects can be computed using the DSM
Identifying potential avalanches	Video from a UAS of snow gullies and chutes can be used to identify mountain roadways at risk of avalanches
Monitoring unstable slopes	DSMs can be constructed from overlapping aerial images or lidar; DSMs from repetitive flights over an area can be differenced to find ground movements
Crash reconstruction	At a crash scene, overlapping aerial images from a UAS can be mosaicked and converted into 3D point clouds by SfM algorithms; could also survey scene using lidar on UAS

2.3.2 Current Civil/Commercial Use

In addition to the transportation sector, many other industries are using drones to complete a wide range of tasks. The 2016–2036 FAA Aerospace Forecast Report argues that understanding the current distribution of drone usage is important to establishing effective and beneficial regulations that help to promote a safe drone industry (FAA 2016a). Figure 2.4 presents the distribution of drone ownership within the top five markets for drone usage.

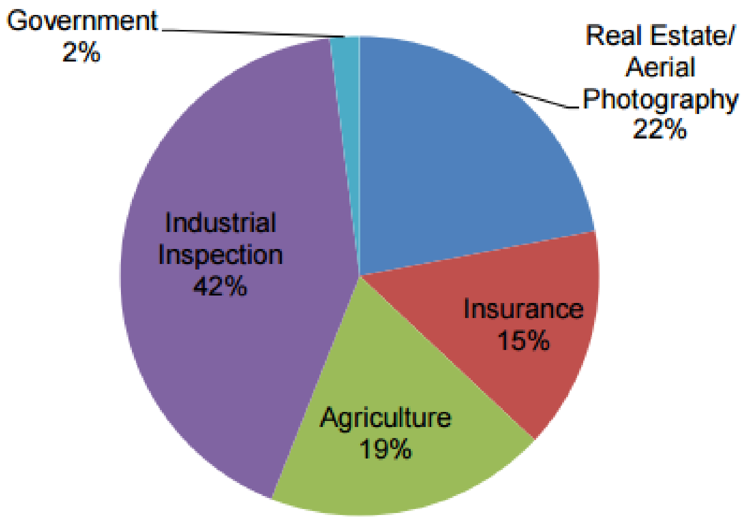


Figure 2.4: Top five drone commercial markets, according to the FAA (FAA 2016a)

Even within broad markets, there are various specific uses for commercial drones. Figure 2.5 summarizes the six primary industries that were researching and implementing drones, and the specific tasks that drones assisted in completing, as reported by Frost and Sullivan in 2007. As drones become more ubiquitous and the legal issues surrounding them are clarified, commercial uses of drones will continue to grow.

Government • Law enforcement (Police, Civil Security • Border Security • Coastguard • Transportation Departments • Academic Research	**Fire Fighting** • Forest fires • Other major incidents • Emergency rescue (e.g. Mountain rescue)	**Energy Sector** • Oil and gas industry distribution infrastructure • Electricity grids/distribution networks
Agriculture, Forestry, and Fisheries • Environmental monitoring • Crop dusting • Optimizing use of resources	**Earth Observation and Remote Sensing** • Climate monitoring • Aerial photography, map-ping, and surveying • Seismic Events • Major incident and pollution monitoring • Landslide monitoring	**Communications and Broadcasting** • VHALE platforms as proxy-satellites • MALE / S/MUAS as short term, local communication coverage

Figure 2.5: Summary of drone use in various industries (modified from Frost and Sullivan 2007)

2.3.3 Recreational/Hobby Use

The FAA categorizes sUAS that are not owned or operated by a commercial entity under the broad category of "model aircraft" intended for recreational and hobby use. This definition applies to unmanned aircraft that meet the following criteria (FAA 2012):

- Capable of sustained flight in the atmosphere
- Flown within the visual line of sight of the person operating the aircraft
- Flown for hobby or recreational purposes

Hobby and recreational uses of drones have fewer FAA regulations (see Section 2.4.1 for more details), although the FAA does provide guidance documentation for applicable rules and registration requirements for recreational drone pilots on its website (FAA 2017a). A few organizations have been established for individuals interested in the hobby and recreational use of drones, for example:

- **Academy of Model Aeronautics:** Founded in 1936, this group seeks to promote the sport of model aviation as a recreational activity by educating its members and publishing documents related to recreational drone use. The group has over 195,000 members and has chartered over 2,500 model airplane clubs across the United States (Academy of Model Aeronautics 2017).
- **US Drone Racing Association:** This group promotes, organizes, establishes guidelines, and encourages participation in the emerging sport of drone racing in the United States (US Drone Racing Association 2015).

The numbers of groups and organizations related to drones will increase as hobby and recreational uses for drones continue to expand.

2.3.4 Issues in Drone Use

Given the rapid increase in drone use, it is not surprising that several issues have arisen from inappropriate or unsafe drone use. As drones become more prevalent, these issues will continue to increase in frequency. As the increase in the number of drones is a relatively recent development, there is no available research regarding the frequency, types, and mitigation measures of drone incidents. However, several recent incidents provide a glimpse into the types of issues can be expected as drones become more popular. Table 2.7 provides a short summary and details from several drone incidents that have been reported by the news media.

Table 2.7: Recent Examples of Incidents Involving Drones

INCIDENT	DATE	REPORTING ORGANIZATION	SUMMARY
Drone hits landing airliner	April 2016	BBC (2016)	A British Airways plane was struck by a drone while approaching London's Heathrow Airport. The incident is still under investigation.
Drone crashes on White House lawn	October 2015	USA Today (Jansen 2015)	A man flying a drone attempted to photograph the Washington Monument.
Handgun fired from a drone	July 2015	CBS News (2015)	A video from Connecticut showed a handgun being fired from a drone. No state laws cover this situation, and the FAA investigated whether this incident violated any federal regulations.
Drone carrying illegal drugs crashes	January 2015	NBC San Diego (McVicker 2015)	A drone carrying 6 lb of crystal meth flew across the border from Mexico into the United Sates and crashed into a parking lot. This was the first confirmed use of a drone to smuggle drugs across the U.S. border.

Many of these cases (e.g., drones flying in sensitive areas, such as Washington D.C. or near an airport) occurred despite existing FAA restrictions that define those flight activities as illegal. The FAA releases an annual report of drone sightings by pilots, air traffic controllers, and other citizens. The 2016 report indicated a dramatic increase in drone sightings from 2014 to 2015 (FAA 2016b), indicating an increase in the number of near-misses involving drones, especially near airport infrastructures. Limited resources are available to educate the public regarding safe drone use or to enforce existing regulations effectively, making prevention of future drone incidents difficult.

2.3.5 Prevalence of Drones

In December of 2015, the FAA began to require registration of hobby and commercial drones, enabling the agency to gather statistics about the prevalence of drones in the United States. As of February 2017, more than 700,000 drones had been registered, including more than 660,000 hobby drones and 43,000 commercial drones (Sharman 2017) (Figure 2.6).

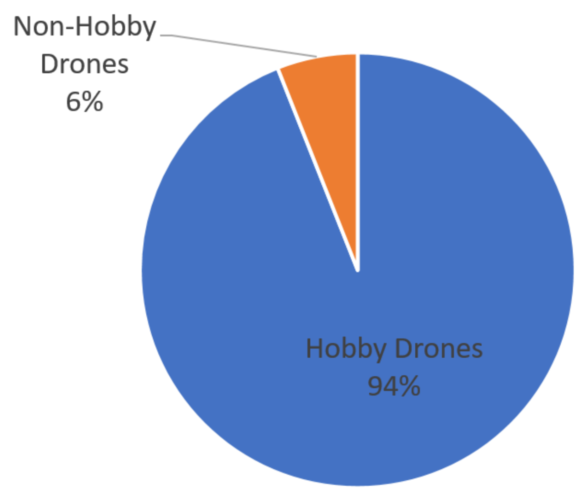


Figure 2.6: Percentages of hobby vs. non-hobby drone registrations (Improdrone 2017)

The FAA data also identified the state of registration. Figure 2.7 shows a color-coded map of the United States showing the number of drones registered per capita in each state. Table 2.8 lists numbers of drone registrations for the 10 states with the highest drone registrations per capita.

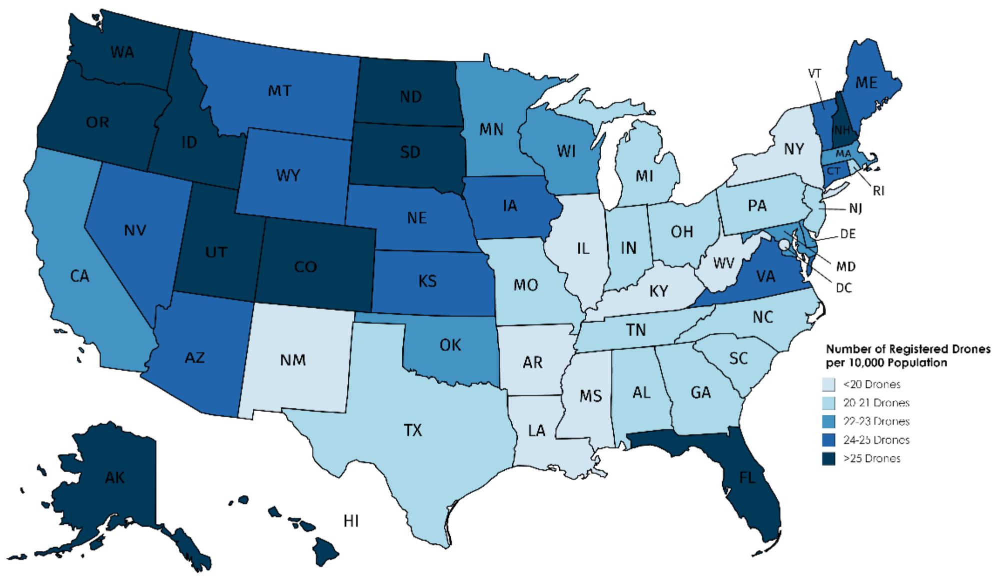


Figure 2.7: Drone registrations by state as of February 2017 (Sharman 2017, Giannekas 2017)

Table 2.8: Top 10 States by Drone Registration Per Capita as of February 2017 (Sharman 2017)

RANK	STATE	DRONE REGISTRATIONS PER 10,000 POPULATION	TOTAL DRONE REGISTRATIONS
1	Alaska	38	2,780
2	Hawaii	36	5,162
3	Utah	32	9,288
4	Colorado	31	16,732
5	New Hampshire	30	3,949
6	Washington	29	20,718
7	Oregon	29	11,525
8	Florida	27	54,190
9	North Dakota	27	1,978
10	Idaho	26	4,314

Oregon ranks seventh in number of registered drones per capita. The Pacific Northwest as a whole has a high drone registration rate, with Alaska, Washington, and Idaho making the top 10 at first, sixth, and tenth, respectively.

2.3.6 Potential Future Uses of Drones

Although technological and regulatory issues have limited the use of drones, the FAA is committed to allowing the expanded use of drones. With technological advancements enabling improved drone reliability, the FAA hopes to relax regulations, such as the requirement that the operator maintain a visual line of site to the drone at all times (FAA 2016a). One of the most publicized possible uses of drones is their implementation for rapid delivery. Relaxing the line-of-sight restriction would allow this potential use to be fully explored and the drone industry to expand at an even faster rate (FAA 2016a). Several high-profile companies are researching and testing the concept of drone deliveries, with three examples listed below:

- **Amazon Prime Air**: In 2013, the research portion of this service was announced. The goal is to use fully autonomous drones to deliver parcels to customers within 30 minutes of the order (Amazon 2017).

- **Google Project Wing:** This project aims to design and build specialty drones that operate on preplanned routes, allowing drones to avoid other aircraft and make rapid deliveries (X.Company 2017).

- **United Parcel Service (UPS):** The UPS drone delivery service will focus on urgent deliveries (e.g., medical supplies, humanitarian aid) and using drones within warehouses as tools to document and preserve inventory (UPS 2016).

The financial capacity of these organizations suggests that rapid delivery will be a major driver of the future drone industry, although other uses have the potential to become drivers as well.

2.4 EXISTING REGULATIONS

As uses for drones expand, regulations regarding drone use will rapidly evolve. Government policymakers are tasked with regulating drone use to ensure public safety and privacy. In the United States, these regulations are enacted at the federal, state, county, and city levels. The Federal Aviation Act of 1958 grants the FAA regulative authority over the use of airspace in the United States (FAA 1958), which gives the FAA primary authority regarding drone regulation. Some states have additionally passed statues that exceed federal standards and regulations.

2.4.1 Federal Regulations

Federal regulations regarding drone use are developed, administered, and enforced by the FAA, which enforces congressional legislation and develops its own additional regulations. The history of FAA regulations regarding drone use has seen three distinct periods, highlighted in Figure 2.8.

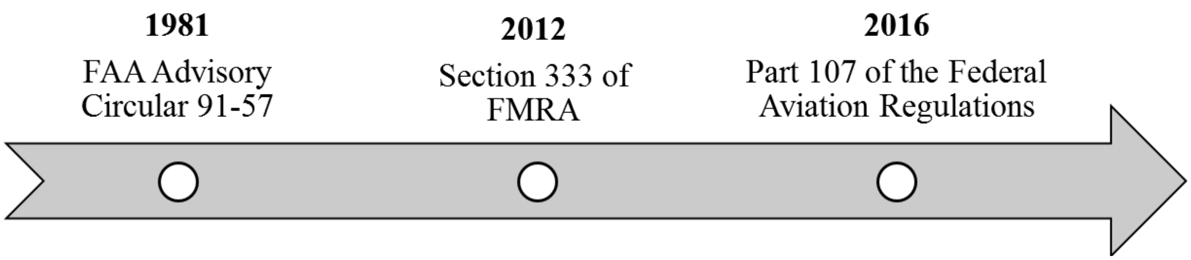


Figure 2.8: Timeline of federal regulations for drones

Federal law has changed over time to reflect current issues in drone technology and usage, with new regulations being passed to replace standards as they become obsolete. Part 107 of the Federal Aviation Regulations is the current governing set of regulations regarding drone use. Table 2.9 briefly describes the requirements imposed by each of the three successive regulatory documents.

Table 2.9: Descriptions of Federal Regulations for Drones (FAA 1981, FAA 2012, FAA 2016c)

REGULATION	FAA ADVISORY CIRCULAR 91-57	SECTION 333 OF FMRA	PART 107 OF THE FEDERAL AVIATION REGULATIONS
Title	Model Aircraft Operating Standards	FAA Modernization and Reform Act (FMRA)	Small Unmanned Aircraft Regulations
Year	1981	2012	2016
Description	• Safety standards for operating model aircraft • Notification of airport operator necessary when flying within 3 miles of an airport • Limits flying to < 400 ft above ground level	• Requires Certificates of Authorization (COAs) for pubic drone activities • COAs provide specific flight guidelines and specifications on a case-by-case basis • Meant as an interim rule until Part 107 could be finalized • Exemptions difficult for private sector	• Applies to non-hobby drones weighing < 55 lb • Requires drones (hobby and commercial) to be registered • Requires pilot certification for commercial drones

The 1981 Advisory Circular and Section 333 of the FMRA are no longer the operational standards governing drone use in the United States. Although in some cases the COAs issued under Section 333 of the FMRA are still active in the transitional period, the new Part 107 regulations are the current governing rules for commercial drone use. Model aircraft, or hobby drones, are still covered under Section 336 of the FMRA. The exception to this coverage is the Part 107 regulations that require all drones to be registered with the FAA before flight. The FAA website (2017a) summarizes the following requirements for hobby and recreational drone use:

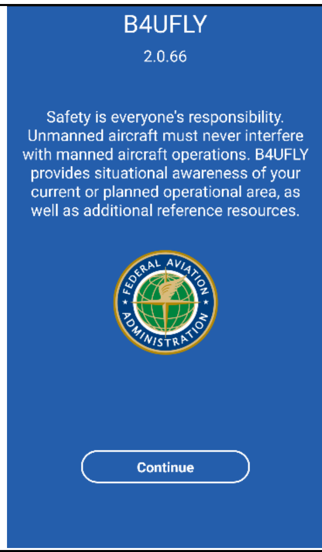
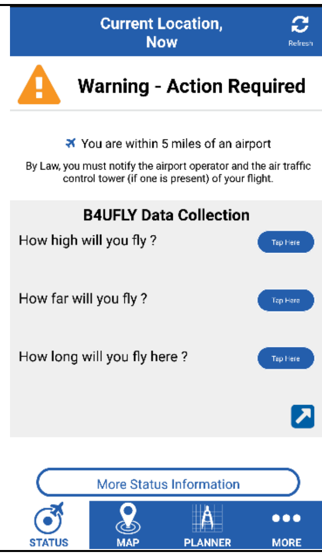
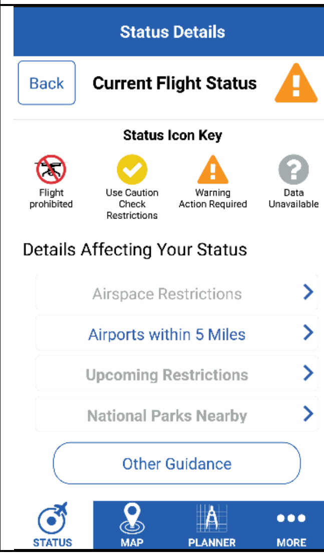
- Register and label the drone according to FAA specifications
- Be 13 years of age or older and a citizen or permanent resident of the United States
- Fly at or below 400 ft, maintaining a line of sight with the drone at all times
- Be aware of FAA airspace restrictions (e.g., near airports)

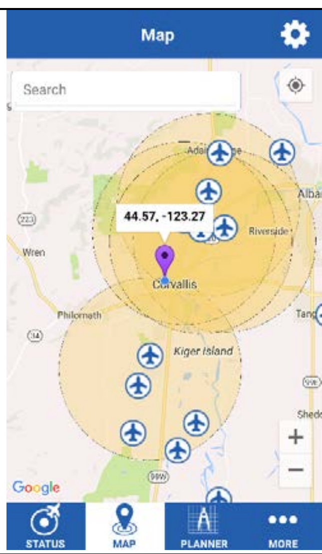
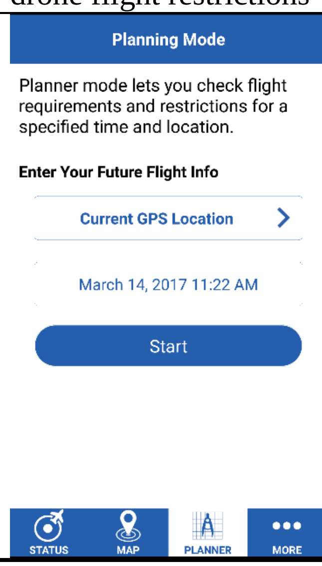
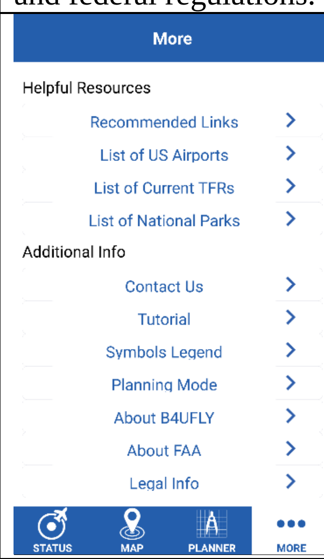
Commercial drones are subject to all of the Part 107 regulations (summarized in Table 2.10). For any of these rules, the operator can petition the FAA for a waiver, which can provide the operator with more flexibility in their drone operations. To communicate the federal regulations regarding drone use (FAA Part 107), the FAA developed a smartphone app for drone operators to determine whether there are restrictions to drone flight based on the time and location of the proposed flight (FAA 2017b). The app is available for both iOS and Android platforms. Table 2.11 summarizes the various pages and associated information that are available to drone operators within the app.

Table 2.10: Summary of FAA Part 107 Regulations (FAA 2016d)

CATEGORY	SUMMARY
Operational limitations	• Must keep the drone ≤ 400 ft above ground level • Must maintain a line of sight with the drone • Must not exceed 100 mph • Must fly during the day • Must not fly over people or moving vehicles • Many limitations can be waived with FAA approval
Pilot responsibilities	• Must be at least 16 years old • Must hold a remote pilot airman certificate, which can be obtained by passing an aeronautical knowledge test from an FAA-approved administrator • Must be vetted by the Transportation Safety Administration (TSA) • Must conduct a preflight inspection to ensure that the aircraft is safe to operate • Must report any incidents resulting in injury or >$500 in property damage to FAA • Separate spotter is no longer required, but recommended.
Aircraft requirements	• Official FAA airworthiness certification not required for drones • Pilot responsible for ensuring drone is able to be safely operated
Model aircraft	• Part 107 does not apply to model aircraft • Model aircraft must be registered with the FAA

Table 2.11: Visual Summary of the FAA B4UFLY Smartphone App (FAA 2017b)

<table>
<tr><th>TITLE</th><th>STARTUP</th><th>STATUS</th><th>STATUS DETAILS</th></tr>
<tr><td>Description</td><td>Page display when the app is first opened to provide a summary to the user</td><td>Uses user location to determine status of flying in the area</td><td>Provides the circumstances of warnings, if present.</td></tr>
<tr><td>Graphic</td><td>
</td><td>
</td><td>
</td></tr>
</table>

<table>
<tr><th>TITLE</th><th>MAP</th><th>PLANNER</th><th>MORE</th></tr>
<tr><td>Description</td><td>Provides a visual of potential restrictions to drone flight, like airports</td><td>Allows user to enter a time and location to determine potential drone flight restrictions</td><td>Provides additional resources for understanding the app and federal regulations.</td></tr>
<tr><td>Graphic</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Federal regulations regarding drone use will continue to evolve and expand. In some cases, as technology continues to advance, regulations may become less restrictive. For example, the FAA is currently investigating the possibility of commercial and hobby drones being used beyond the pilot's line of sight. Currently, special waivers can be granted to allow this type of flight, but general flights must still adhere to this restriction (FAA 2016a). However, other restrictions may be increased or newly developed as new safety issues from the use of drones emerge.

2.4.2 State Regulations

Despite the emphasis on federal regulation, state governments and other agencies have begun to implement additional regulations regarding drone use. The following sections summarize current regulations and policies in Oregon and surrounding states.

2.4.2.1 Oregon Regulations and Policy

Oregon has been active in producing legislation and policies related to drone operations. Table 2.12 summarizes Oregon legislative regulations implemented through 2016.

Table 2.12: Summary of Drone Regulations in Oregon (NCSL 2017)

REGULATION/ STATUTE	YEAR	DESCRIPTION
HB 2710	2013	• Defines a drone as an unmanned flying machine • Allows law enforcement with warrants to use drones • Requires government agencies to register any drones with the Oregon Department of Aviation • Prohibits weaponizing a drone
HB 2534	2015	• Requires development of rules prohibiting drone use for angling, hunting, or trapping, or for interfering with someone who is lawfully angling, trapping, or hunting
HB 4066	2016	• Regulates use of data collected by state agencies via drone • States that weaponizing a drone is a class A misdemeanor • Prohibits use of drones near fenced-off or enclosed critical infrastructure facilities
SB 5702	2016	• Specifies fees for registration of drones owned by government agencies

In addition to legislative action regarding drones, the following individual state departments have published internal reports and documents related to drone operations:

- **Department of Aviation:** In 2014, the Oregon Department of Aviation published a report to the State Legislature regarding the current status of federal guidelines for drones. It recommended that the state wait to pass a rule requiring drone registration in anticipation that the FAA would enact such a rule (Swecker undated).

- **Department of Transportation:** ODOT has adopted an internal policy regarding drone use by department employees, contractors, and consultants. This policy primarily focuses on the storage, access, and sharing of data collected by drones. The policy establishes that ODOT drone operations will be conducted in accordance with the ODOT UAS Operations Manual (ODOT 2017), reinforcing that ODOT will operate under FAA Part 107 regulations. The manual summarizes federal regulations and direction related to specific Oregon statues, policies, and issues (Singh 2017).

2.4.2.2 Bordering State Regulations and Policy

States bordering Oregon likewise have tackled issues related to drone operations, with Table 2.13 summarizing regulations implemented through 2016. Because drone legislation is a current issue, existing regulations are changing frequently. Fortunately, the National Conference of State Legislatures (NCSL) maintains an up-to-date list of the drone legislation implemented by state governments (URL: http://www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx).

Table 2.13: Summary of Drone Regulations in States Bordering Oregon (NCSL 2017)

STATE	REGULATION/ STATUTE	YEAR	DESCRIPTION
Alaska	HB 255Z	2014	• Allows law enforcement with warrants to use drones • Authorizes the University of Alaska to develop a drone training program
	HJR 05	2015	• Recognizes the Academy of Model Aeronautics for establishing safety guidelines for drone use
	HCR 017B	2016	• Grants state land for use in research and testing of drones
	HB 0256Z	2016	• Requests the Department of Fish and Game evaluate use of drones for survey work
	HCR 06	2013	• Creates a legislative task force to create recommendations and legislation for limiting UAV use to protect privacy
California	SCR 16	2013	• Recognizes benefits of the drone industry in California
	AB 856	2015	• Prohibits unauthorized recording or photography of private property and its occupants
Idaho	S 1134	2013	• Allows law enforcement with warrants to use drones • Establishes guidelines for use by private citizens, including penalties for improper use
	SCR 103	2013	• Recognizes benefits of the drone industry in Idaho
	S 1213	2016	• Prohibits use of UAS for hunting, molesting, or locating game animals, game birds, and furbearing animals
Nevada	SCR 7	2013	• Recognizes benefits of the drone industry in Nevada
	AB 507	2013	• Appropriates $4 million for a UAV program if Nevada is a FAA test site
	AB 239	2015	• Prohibits weaponizing a drone • Requires government agencies to register drones • Prohibits use of drones near critical infrastructure

There are a few interesting trends in the legislation regarding drone use in Oregon and surrounding states. Many states, including Oregon and Nevada, have enacted legislation that prevents drones from being flown near critical infrastructure. However, highway infrastructures, including bridges and tunnels, are not included in the lists of critical infrastructures in these statutes. A 2016 report from the NCSL regarding all drone legislation does not mention roadways or highways. Some transportation infrastructures, such as ports and rail yards, are defined as critical infrastructures in some states, but highway infrastructure is not specifically mentioned (NCSL 2016). Most of the state regulations provide direction to state government agencies regarding their use, registration, and operation of drones. Most laws require law enforcement to have a warrant before using a drone to collect information for an investigation.

In addition to direct legislation, there are state-produced publications regarding drone use from surrounding states, including the following in the states of Alaska and Washington:

- **Alaska:** The UAS Legislative Task Force (2015) developed a set of guidelines for drone use, focusing on protecting the privacy of Alaskan citizens. This report specifically states that drones could be a distraction to drivers.

- **Washington:** The Washington DOT published a document entitled "Washington State Policy Guidelines for Unmanned Aircraft Systems" to provide guidance to policymakers as they develop drone-related policies. The report highlights that drone use by state agencies should not infringe on Constitutional rights or violate federal laws (Alben undated).

The landscape and breadth of legislation at the state and federal levels will continue to expand as governments try to balance promoting the industry with maintaining safety.

2.5 DRIVER DISTRACTION

Drone operation in close proximity to surface transportation facilities has the potential to result in driver distraction (UAS Legislative Task Force 2015). The following sections explore different elements of driver distraction, including types and locations of distractions, and the use of driving simulation as a valid tool for evaluating driver distraction.

2.5.1 Distraction Types

The NHTSA defines distracted driving as "any non-driving activity a person engages in while operating a motor vehicle. Such activities have the potential to distract the person from the primary task of driving and increase the risk of crashing" (NHTSA undated). End Distracted Driving (EndDD), an organization committed to raising awareness of distracted driving and preventing distracted driving incidents, provides the following definitions (and examples) of three types of distractions (EndDD 2017):

- *Manual distractions* occur when you move your hands away from the task of controlling the vehicle (e.g., reaching for your phone in your pocket).

- *Visual distractions* occur when you focus your eyes away from the road (e.g., looking at your phone and reading a text message from a friend inviting you to a party).
- *Cognitive distractions* occur when your mind wanders away from the task of driving (e.g., thinking about what food you will bring to the aforementioned party).

The problem with distracted driving is not necessarily the distraction itself, but the accidents that are caused as a result of the distraction. The NHTSA has published reports on distracted driving statistics and safety issues that occur as a result of distracted driving. In 2011, 10% of fatal crashes and 17% of injury crashes were distraction-affected, meaning that the driver was identified as distracted at the time of the crash (NHTSA 2013). In 2015, distraction-affected vehicle crashes accounted for 3,477 deaths and more than 391,000 injuries (NHTSA 2017).

2.5.2 External Distractors

There are many sources of visual, cognitive, and manual distractions. Regan et al. (2009) identified six major sources of distraction while driving. Five of these sources (things brought into vehicle, vehicle systems, vehicle occupants, moving objects or animals in the vehicle, and internalized activities) are considered to be internal distractions because the source of the distraction comes from inside the vehicle. Internal distractors can result in all three distraction types. An external distraction occurs when the distraction originates from outside the vehicle, beyond the driver's reach. External distractors commonly result in only visual and cognitive distractions. Regan et al. (2009) lists the following events and objects as external distractions: animals, architecture, advertising billboards, construction zone/equipment, crash scenes, incidents, insects, landmarks, road signs, road users, scenery, vehicles, and weather. Although are not specifically included in this list, flying objects, such as drones, could result in similar distractions as other categories of dynamic external distractions.

Stutts et al. (2001) and Stutts et al. (2005) determined that between 23% and 29% of distraction-related crashes are influenced by external distractions, making them the largest single category of influence for distraction-related crashes. External distractors result in glances away from the roadway. A report by Klauer et al. (2006), which utilized data from the 100-Car Naturalistic Driving Study at Virginia Tech, sought to quantify the safety impact of glances away from the roadway. The authors concluded that a total eyes-off-road glance of greater than 2 seconds at least doubles a driver's near-crash/crash risk. However, as noted by Milloy and Caird (2011), despite the large percentage of crashes from external distractions, most studies have explored distractions due to internal distractors, such as cell phones and navigations systems.

2.5.3 Distraction Simulator Studies

Driving simulators enable quantification of the effects of external distractors. Distraction research frequently uses driving simulator environments because of the ability to examine many performance measures in a realistic but safe environment (Young et al. 2011). Given the hazards of distracted driving, the controlled environment of a driving simulator allows a valid scientific study to be conducted without risking the safety of test participants. Furthermore, driving simulator environments have good validity, particularly relative validity (Young et al., 2011). Relative validity occurs when similar magnitudes and directions of change are recorded in the simulator and real-world environments. This validity generally increases when the simulator has higher fidelity, as such simulators convey a higher sense of realism in the virtual environment.

Several previous studies evaluated external distractions, particularly roadside billboards, in a simulator environment. Bendak and Al-Saleh (2010) and Edquist et al. (2011) found that billboards altered drivers' visual attention and negatively affected driving performance, based on measures such as response time, headway, and lateral position. Milloy and Caird (2011) compared the distraction effects of standard roadside vs. video billboards. Glances at video billboards posed an increased distraction risk by increasing response time and decreasing headway distance. Antonson et al. (2014) determined that the presence of roadside objects had a slight speed-reducing effect. When objects were close to the edge of the road, they also affected the lateral position of the driver. The Milloy and Caird (2011) article on external distractors examined the effects of video billboards and wind farms on driver distraction. This study found that drivers looked at the turbines of the roadside wind farms and, consequently, reduced their speeds. However, their lateral position was not affected. Ultimately, these studies indicate that various external distractions could be explored through the use of a high-fidelity simulation environment.

2.6 SUMMARY

Technological advances have enabled drones to become financially viable for commercial and recreational purposes, expanding their use beyond the military. Drones are an emerging technology with various potential commercial and recreational uses. To ensure that the industry continues to grow and that drones will be used in a safe manner, government entities have begun to regulate their use. Most regulation has been at the federal level for commercial drones, but states have also passed legislation to regulate commercial and recreational drone use. However, there is no direct guidance regarding the proximity of drones to roadways. Regulations are limited to preventing drones from being directly above moving vehicles. Nevertheless, a legislative task force in Alaska identified that drones may be a distraction to drivers when they are flown near roadways.

The presence of distractors, including distractors external to the vehicle, can pose an important hazard to drivers. One method of evaluating potential distractions in a safe environment is through the use of driving simulation. Several studies regarding external distractors have been completed in driving simulator environments. No literature relating specifically to the distraction effects of drones (or similar) was found in the course of this literature review. The combination of increased drone use and potential safety issues involving driver distraction suggests a need to determine the potential for drones to distract drivers and degrade their performance.

Based on a review of literature related to similar types of external distractors, it is likely that drones will primarily generate visual distractors that could escalate to cognitive distractions. Similar visual distractors considered in previous research resulted in measured changes in driver performance, including visual attention, speed, and lateral position of the vehicle. Hence, these dependent measures will be considered in the experimental design.

2.7 RESEARCH QUESTIONS

Based on the current literature and existing regulations related to drone operations, there are gaps in knowledge relating to the potential safety concerns of drone operations near roadway infrastructures. Thus, the research questions were developed from a combination of the project's research objectives and the findings of the literature review. The following sections list the nine research questions that guided the experimental design and data analysis of this investigation.

2.7.1 Visual Attention

Visual attention of motorists was measured by eye-movement data, collected with eye-tracker technology, as described in Chapter 3.0 Methodology. The potential influence of the conditions described in these questions guided the development of experimental factors.

- *Research Question 1 (RQ_1):* Is a motorist's visual attention on a drone operation influenced by proximity of the drone operation to the roadside?
- *Research Question 2 (RQ_2):* Is a motorist's visual attention on a drone operation influenced by characteristics of the physical environment surrounding drone operation?
- *Research Question 3 (RQ_3):* Is a motorist's visual attention on a drone operation influenced by the flight pattern of the drone?

Answers to these research questions are detailed in Section 4.2 Visual Attention.

2.7.2 Lateral Position

The lateral position of the vehicle was measured by the driving simulator equipment, as described in Chapter 3.0 Methodology. The potential influence of the conditions described in these questions guided the development of the experimental factors.

- *Research Question 4 (RQ_4):* Is the lateral position of a motorist's vehicle influenced by the proximity of the drone operation to the roadside?
- *Research Question 5 (RQ_5):* Is the lateral position of a motorist's vehicle influenced by characteristics of the physical environment surrounding the drone operation?
- *Research Question 6 (RQ_6):* Is the lateral position of a motorist's vehicle influenced by the flight pattern of the drone?

Answers to these research questions are detailed in Section 4.3 Lateral Position.

2.7.3 Speed

Vehicle speed was measured by the driving simulator equipment, as described in Chapter 3.0 Methodology. The potential influence of conditions described in these questions guided the development of the experimental factors.

- *Research Question 7 (RQ_7):* Is the speed of a motorist's vehicle influenced by the proximity of the drone operation to the roadside?

- *Research Question 8 (RQ_8):* Is the speed of a motorist's vehicle influenced by characteristics of the physical environment surrounding the drone operation?

- *Research Question 9 (RQ_9):* Is the speed of a motorist's vehicle influenced by the flight pattern of the drone?

Answers to these research hypotheses are detailed in Section 4.3.

3.0 METHODOLOGY

This chapter describes the equipment and experimental design that were used to evaluate the research questions in the OSU driving simulator.

3.1 EXPERIMENTAL EQUIPMENT

The experimental design and established experimental protocols were selected as the most appropriate means to address the research questions of interest. This approach is grounded in accepted practice (Fisher, et al. 2011) and leverages unique research capabilities at OSU. Two primary tools were used for this experiment, the OSU driving simulator and the Applied Science Laboratories (ASL) eye-tracking system, which are described in detail in the following sections.

3.1.1 Driving Simulator

The OSU driving simulator facility consists of two primary components: a desktop development simulator and a full-scale high-fidelity motion-based simulator. Researchers first built and test drove the environment using the desktop development simulator. The multimonitor platform of the desktop development simulator (Figure 3.1), with the incorporated steering wheel and floor pedals, is useful for creating, coding, and testing developed scenes. This desktop development simulator allows for quick troubleshooting during environment development.

Figure 3.1: Operator workstation for the driving simulator. *Left*: Designing an experiment in the Internet Scene Assembler with Java script. *Right*: A researcher evaluating a newly designed environment.

The full-scale OSU driving simulator is a high-fidelity motion-based simulator comprising a full 2009 Ford Fusion cab mounted above an electric pitch motion system capable of rotating ±4°. The vehicle cab is mounted on the pitch motion system with the driver's eye point located at the center of the viewing volume. The pitch motion system allows for accurate representation of acceleration or deceleration (Swake et al. 2013). Three liquid crystals on silicon projectors with a resolution of 1,400 × 1,050 are used to project a front view of 180° × 40°. These front screens measure 11 ft × 7.5 ft. A digital light-processing projector is used to display a rear image for the driver's center mirror. The two side mirrors have embedded LCD displays. The update rate for projected graphics is 60 Hz. Ambient sounds around and internal sounds in the vehicle are modeled with a surround sound system. The computer system includes a quad-core host running Realtime Technologies *SimCreator* Software (Version 3.2) with a 60-Hz graphics update rate. The simulator software is capable of capturing and outputting accurate values for performance measures (speed, position, brake, and acceleration). Figure 3.2 shows views of the simulated environment created for this experiment from inside (left) and outside (right) the vehicle.

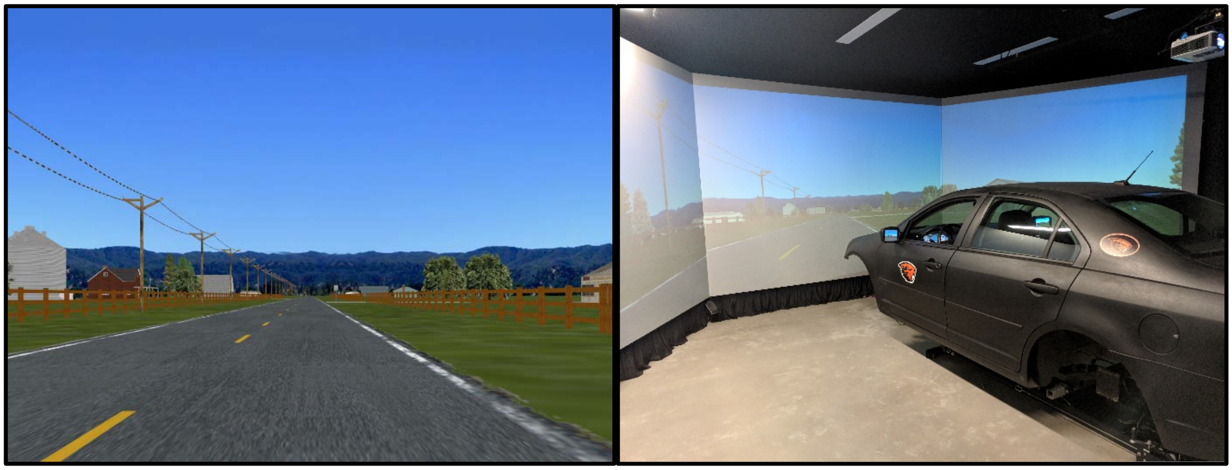


Figure 3.1: Simulated environment in the OSU driving simulator, from the participant's perspective inside (*left*) and from outside (*right*) the vehicle.

The full-scale driving simulator is controlled from the operator workstation (Figure 3.3). The full driving simulator is located in a separate room from the desktop development simulator and the full simulator operator workstation. This separation prevents participants in the vehicle from being affected by visual or audible events from researchers during the experiment.

Figure 3.3: Operator workstation for the full-scale driving simulator. Monitors are shown displaying SimObserver (left), and the simulated environment (center) or vehicle dashboard (right) as seen in the vehicle.

The virtual environment was developed by using Simulator software packages, including *Internet Scene Assembler* (ISA) *(Version 2.0)*, *SimCreator*, and *Blender (Version 2.45)*. The simulated test track was developed in ISA by using Java Script-based sensors that activate the motion of the roadside drone operations when the participant vehicle approaches.

3.1.1.1 Simulator Data

The following parameters describing the participant vehicle were recorded at roughly 60 Hz (60 times per second) throughout the duration of the experiment:

- Time – Maps changes in the speed and position of the participant vehicle relative to the location of the drone;
- Instantaneous speed of participant vehicle – Identifies changes in speed when the driver approaches a drone;
- Instantaneous position of participant vehicle – Estimates the lane position of the participant vehicle when approaching a drone;
- *SimObserver* data – The driving simulator is equipped with five cameras positioned at various viewing angles to observe the actions of participants when

approaching a drone. Figure 3.4 shows the various camera views and screen captures that were recorded by *SimObserver (Version 2.02.4)*.

Figure 3.4: Screenshot of the six views from SimObserver. Top left: Simulated scene as projected on the screen. Top center: View of the driver's upper body and hands on the steering wheel. Top right: View of the acceleration and brake pedals in the vehicle. Bottom left: View of the driver's face. Bottom center: View of steering wheel and dashboard. Bottom right: View of the entire simulator from outside the vehicle.

3.1.1.2 Simulator Sickness

Simulator sickness is a phenomenon wherein a person exhibits symptoms similar to motion sickness due to use of a simulator (Fisher et al. 2011; Owens and Tyrrell 1999). Symptoms can include headache, nausea, dizziness, sweating, and in extreme situations, vomiting. Although there is no definitive explanation for simulator sickness, one widely accepted theory, cue conflict theory, suggests that it arises from the mismatch of visual motion cues and physical motion cues, as perceived by the vestibular system (Owens and Tyrrell 1999).

3.1.2 Eye Tracker

In conjunction with the driving simulator, an eye-tracking system was used to record where participants were looking while driving in the simulator. Eye-tracking data were collected with the ASL Mobile Eye-XG platform (Figure 3.5), which allows the user unconstrained eye and head movements. A 30-Hz sampling rate was used, with an accuracy of 0.5–1.0° (OSU Driving and Bicycle Research Lab 2011). The participant's gaze was calculated based on the correlation between the participant's pupil position and the reflection of three infrared lights on the eyeball.

Eye movement consists of *fixations* and *saccades*. *Fixations* occur when the gaze is directed towards a particular location and remains still for some period of time (Green 2007; Fisher et al. 2011). *Saccades* occur when the eye moves between *fixations*.

The ASL Mobile Eye-XG system records a fixation when the participant's eyes pause in a certain position for more than 100 milliseconds. Quick movements to another position (saccades) are not recorded directly but are calculated based on the dwell time between fixations. Total dwell times are recorded by the equipment as the sum of the time of fixations and saccades consecutively recoded within an area of interest (AOI).

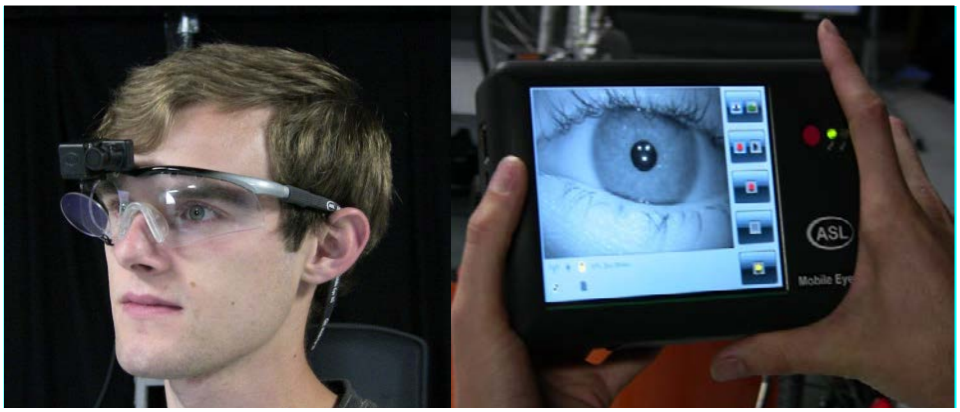


Figure 3.5: OSU researcher demonstrating the Mobile Eye XG Glasses (left) and Mobile Recording Unit (right).

3.2 EXPERIMENTAL DESIGN

To address the research questions related to the distraction potential of drone operations near roadway infrastructure, an experiment was designed using the OSU driving simulator and the eye-tracker equipment. Current FAA policy requires that the pilot maintain a line of sight with the drone during all flight operations. To achieve this goal, the pilot will often work with a spotter (required for drones operated with First Person View technology) (FAA 2016d).

For the sake of this experiment, a single definition for "drone operation" was applied to the simulator scenarios. This definition included a single quadcopter drone measuring approximately 3 ft in length and width. With each drone, two individuals were placed side by side facing the drone to represent the pilot and spotter. A set of four different avatars were used in a total of six different operator pair configurations. Figure 3.6 provides an example of a drone operation as seen in the simulator from the perspective of an approaching driver.

Figure 3.6: Example drone operation configuration in the simulator environment

3.2.1 Coding Drone Flight Path

One aspect of designing the drone operation was coding the drone's flight path. The *ISA* and *Sim Creator* software packages do not have a built-in function to allow objects to move in three dimensional space. The built-in functions have objects move exclusively in two dimensions along the ground (e.g. a vehicle). Researchers developed unique JavaScript code for the drone to execute a three dimensional flight path. The code allowed the location of the drone to be moved to any location on a frame by frame basis. This gave researchers the ability to adjust the location and the speed of the drone along its flight path in three dimensional space. The JavaScript code provided researchers additional flexibility when developing the independent variables for this experiment.

3.2.2 Experimental Variables

3.2.2.1 Independent Variables

Three independent variables were included in the experiment: lateral offset, flight path, and land use. These variables were selected by the research team in collaboration with the ODOT Technical Advisory Committee (TAC) to help answer the research questions.

The first independent variable, "lateral offset," had three levels: 0 ft, 25 ft, or 50 ft from the right edge of the pavement. The 0-ft offset referred to the drone located directly beside the roadway. Drone operators were located at the offset, and the center of the drone path was located at approximately this offset. Although there was some variability in offset depending on the flight path (the second independent variable), flight paths were coded to have the drones traverse parallel to the roadside to maintain similar offsets. Drones were coded such that they never flew directly over the roadway, even in the 0-ft offset condition, to ensure compliance with the FAA Part 107 requirement that drones not be flown over nonparticipants (i.e., drivers or bicyclists in the roadway) (FAA 2016d).

The second independent variable, “flight path,” had three levels: takeoff, scanning, and racing. These levels were chosen to represent likely operations to be undertaken by drones based on the literature review. The takeoff flight path initiated with a drone located adjacent to the operators and followed a vertical takeoff path at a constant rate. The flight path was coded so that approaching drivers would not see the takeoff drone more than 6 ft above the ground. The scanning drone was placed at a constant height of 32 ft above the ground and was assigned a back-and-forth scanning pattern parallel to the roadway, which it traversed at a constant rate. In contrast, the racing drone was given a more erratic flight path that moved in the x, y, and z directions. The average height of the racing drone was approximately 26 ft above the ground with a range of between 21 and 31 ft above the ground. The speed of the flight path varied while the operators themselves remained stationary. A registered drone pilot was consulted in developing flight paths for this experimental design, so that the coded movements replicated real drone movements as much as possible within the confines of the driving simulator.

The final independent variable, “land use,” had two levels: rural and urban. The land use variable encompassed roadway and track characteristics.

For the rural setting (Figure 3.7), the roadside included intermittent fencing and light residential and agricultural development. The cross-section of the roadway consisted of one 12-ft traffic lane in each direction. A dashed yellow centerline and a solid white edgeline were constantly present, but there was no paved shoulder or sidewalks. The speed limit was posted at 35 mph. Light ambient traffic was included in the simulation, and the layout of the track included occasional traffic signals.

Figure 3.7: Screen capture of a sample rural environment coded in the simulator.

For the urban setting (Figure 3.8), the roadside was light-to-medium-density commercial and industrial development. The cross-section of the roadway consisted of two 12-ft traffic lanes in each direction with no median. A double yellow centerline and solid white edgeline were constantly present. A small 1-ft paved shoulder was present on the roadway. There were constant 6.5-ft-wide pedestrian sidewalks on both sides of the road. The speed limit was posted at 35 mph. Light ambient traffic was included, and the layout of the track included occasional traffic signals spaced approximately every 3/4 mile.

Figure 3.8: Screenshot of a sample urban environment coded in the simulator

3.2.2.2 Dependent Variables

Three primary dependent variables were observed based on the research questions and independent variables selected for this experiment. Visual attention was recorded from the eye-tracking equipment as drone-induced glances away from the roadway. Speed and lateral position of the participant vehicle were observed from the simulator data to determine how participants slowed down or shifted lane position while approaching a drone operation. These changes can demonstrate potentially unsafe driver behavior, such as sharp braking or crossing a lane line into conflicting traffic.

3.2.3 Factorial Design

A factorial design was chosen for this experiment to enable exploration of all three independent variables separately. The factorial design for the three variables, each with two or three levels, resulted in the inclusion of 18 scenarios, which were presented within subjects. The within-subject design provides advantages of greater statistical power and reduced error variance associated with individual differences (Cobb 1998). However, one fundamental disadvantage of the within-subject design is the existence of “practice effects,” caused by practice, experience, and growing familiarity with procedures as participants move through the sequence of conditions. To control for practice effects, the order of the presentation of scenarios to participants needs to be randomized or counterbalanced (Girden 1992). Table 3.1 summarizes the independent variables and their associated levels in the factorial design.

Table 3.1: Experimental Variables and Levels

VARIABLE	ACRONYM	CATEGORY	LEVEL	LEVEL DESCRIPTION
Lateral offset	LO	Discrete	0	0 ft
			1	25 ft
			2	50 ft
Flight path	FP	Nominal (Categorical)	0	Takeoff
			1	Scanning
			2	Racing
Land use	LU	Dichotomous (Categorical)	0	Rural
			1	Urban

3.2.4 Counterbalancing and Presentation of Driving Scenarios

To control for the practice or carryover effect, the order of the scenarios was counterbalanced. Four different track layouts were developed and presented in random order to each participant. Randomized, partial counterbalancing was chosen due to its simplicity and flexibility in terms of statistical analysis and number of required participants. Each track had four or five drone operations, and each drone operation was randomly assigned one level for each of the three independent variables. The only exception to this randomization was the land use variable, which influenced roadway geometry. To ensure that land use did not change randomly, two tracks (nine drone operations) were coded in the rural environment (level 0), and two tracks (9 drone operations) were coded in the urban environment (level 1). The other two independent variables were assigned randomly to each drone operation within these tracks.

Table 3.2 presents the configuration layout for each of the 18 drone encounters that were presented to participants, in a randomized order, across four tracks. Figures 3.9 to 3.11 show examples of individual scenarios in the simulator as presented to the drivers. Each drone encounter had one of the levels for each of the three independent variables.

Table 3.2: Track and Drone Configuration Layout

DRONE #	LATERAL OFFSET (LO)	FLIGHT PATH (FP)	LANDUSE (LU)
		Track 1	
1	50 ft	Racing	Rural
2	25 ft	Takeoff	Rural
3	0 ft	Racing	Rural
4	0 ft	Scanning	Rural
		Track 2	
5	0 ft	Takeoff	Rural
6	25 ft	Scanning	Rural
7	50 ft	Takeoff	Rural
8	25 ft	Racing	Rural
9	50 ft	Scanning	Rural
		Track 3	
10	0 ft	Scanning	Urban
11	50 ft	Racing	Urban
12	25 ft	Racing	Urban
13	50 ft	Takeoff	Urban
		Track 4	
14	0 ft	Takeoff	Urban
15	0 ft	Racing	Urban
16	50 ft	Scanning	Urban
17	25 ft	Takeoff	Urban
18	25 ft	Scanning	Urban

Figure 3.9: Example scenario of Drone #5 (rural land use, takeoff flight path, and 0-ft offset)

Figure 3.10: Example scenario of Drone #6 (rural land use, scanning flight path, and 25-ft offset)

Figure 3.11: Example scenario of Drone #11 (urban land use, racing flight path, and 50-ft offset)

3.3 DRIVING SIMULATOR EXPERIMENTAL PROTOCOL

The experimental procedure was carefully designed to reduce occurrence of simulator sickness, such as by providing long tangent sections between curves or small breaks between driving successive grids. The entire data collection process was designed to ensure that all necessary information was recorded efficiently. This section describes the step-by-step procedures of the driving simulator study, as conducted for each individual participant.

3.3.1 Recruitment

A total of 54 individuals, primarily from the community surrounding Corvallis, OR, were test participants in the experiment. The population of interest was licensed drivers; therefore, only drivers with Oregon driving licensure and at least 1 year of driving experience were recruited for the experiment. Participants were required to not wear glasses or have poor vision, to be physically and mentally capable of legally operating a vehicle, and to be deemed competent to provide written, informed consent. Participants were recruited through flyers posted around campus and the surrounding community and through emails sent to different campus organizations and email listservs. Older participants were specifically recruited by email using the Center for Healthy Aging Research registry (LIFE Registry), which includes people 50 years or older who reside in Oregon and wish to volunteer for research studies. Researchers did not initially screen interested participants based on gender; however, once the quota for men or women had been reached, only the gender with the unmet quota was allowed to participate. Although it was expected that many participants would be OSU students, an effort was made to incorporate participants of all ages within the specified range of 18 to 75 years. Throughout the entire study, participant data were kept under double-locked security in compliance with accepted Institutional Review Board (IRB) procedures (Study #7547, see Appendix A). Each participant was randomly assigned a number to remove any uniquely identifiable information from the recorded data.

3.3.2 Informed Consent and Compensation

When the test participant arrived at the laboratory, they received the OSU IRB-approved informed consent document (Appendix B), which described the reasoning behind the study, the importance of participation, and the risks and benefits of the test for the participant. The researcher discussed the document and the overall idea of the experiment with the participant, who was invited to ask questions. The participant was informed that they could stop the experiment at any time for any reason and still receive full compensation ($20 cash) for participating in an experimental trial. To avoid biasing the experiment, participants were not told the specific research hypotheses.

3.3.3 Prescreening Survey

Participants were administered a prescreening survey on their demographics (i.e., age, gender, ethnicity, driving experience, highest level of education, and prior experience with driving simulators) and questions in the following areas:

- *Vision* – Good vision was crucial for this experiment. Participants were asked if they used corrective glasses or contact lenses while driving. Their abilities to see the driving environment clearly and to read visual instructions (displayed on the screen) to stop driving were confirmed.

- *Simulator sickness* – Participants with previous driving simulation experience were asked about any simulator sickness that they experienced. If they had previously experienced simulator sickness, they were encouraged not to participate in the experiment.

- *Motion sickness* – Participants were surveyed about any kind of motion sickness they had experienced in the past. If an individual had a strong tendency towards any kind of motion sickness, they were encouraged not to participate in the experiment.

3.3.4 Calibration Drive

After completing the prescreening survey, participants performed a 5-minute calibration drive. The overall purpose of this drive was to acclimate participants to the mechanics of the vehicle and the virtual reality of the simulator, and to determine if they were prone to simulator sickness. Once seated in the vehicle for the test drive, participants were allowed to adjust the seat, rearview mirror, and steering wheel to maximize comfort and performance while driving. They were instructed to drive and follow all traffic laws as they normally would.

According to Zhao et al. (2015), effective calibration drives introduce the participant to three primary roadway characteristics in the simulator environment: horizontal curves, acceleration and deceleration on a stretch of roadway, and turning at intersections. Figure 3.12 shows the standard calibration drive that was developed for this experiment, which included all three elements. The environment of the calibration drive was simple and did not include any roadside development. Large yellow billboards with arrows were used to instruct the driver on which way to turn at intersections. Before the calibration drive, participants were instructed to follow the arrows on the billboards.

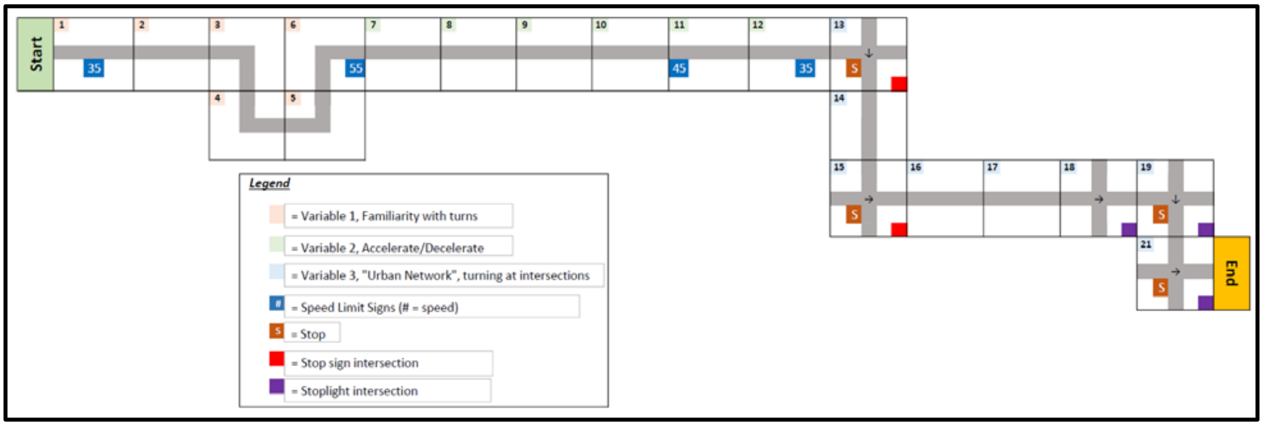


Figure 3.12: Layout of calibration drive

Figure 3.13 shows views from two locations in the calibration drive. Participants who reported experiencing simulator sickness during or after the calibration drive were excluded from the experimental drives.

Figure 3.13: Screenshots of calibration drive in simulation. Left: Approach to a curve near the beginning of the drive. Right: Approach to a signalized intersection, where a yellow billboard indicates a right turn

3.3.5 Eye-Tracking Calibration

After the calibration drive was completed, researchers equipped participants with a head-mounted eye tracker. Participants were directed to look at different locations on a calibration image projected on the forward screen of the driving simulator (Figure 3.14). If the eye-tracking equipment was unable to perform the calibration, which depended on eye position and other physical attributes of the participant, then the experiment was not continued (Four percent of participants in this experiment).

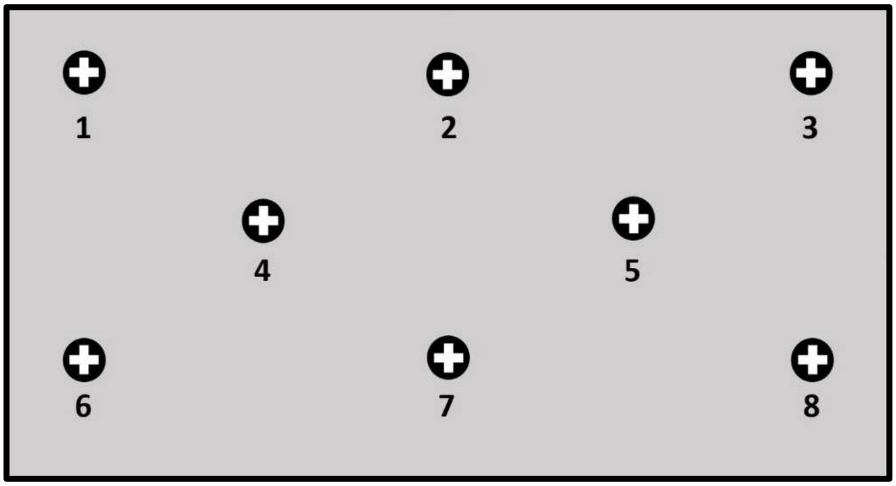


Figure 3.14: Eye-tracking calibration image.

3.3.6 Experimental Drive

After the motorist's eyes were calibrated to the driving simulator screens, they were given brief instructions about the test environment and the tasks that they were required to perform. The experiment was divided into four tracks, which were designed so that the drivers did not have to turn at any of the intersections to simplify the procedure. At the completion of each experimental drive, the researcher instructed the participant to stop the vehicle and ascertained whether the participant was experiencing simulator sickness. The virtual driving course (four tracks) was designed to take 30 to 40 minutes to complete.

3.3.7 Postdrive Survey

As the final step of the experiment, drivers were asked to respond to several questions in a postdrive digital survey, which included questions about their previous experiences with drones, particularly drones near roadways, and their attitudes regarding future drone operations in various land development scenarios near roadways. The survey asked if the participant had experienced any simulator sickness during the experiment. The entire experiment, including the consent process, eye-tracker calibration, and postdrive questionnaire, lasted about 1 hour.

3.4 DATA REDUCTION

Eye-tracking and simulator data for participants were carefully reduced to extract portions corresponding to drone encounters. The following sections describe these processing procedures.

3.4.1 Eye-Tracking Data

After collecting participants' eye-movement data, fixation and dwell data were analyzed by AOI polygons with the *ETAnalysis* software suite. For this process, researchers watched each video segment that included a drone encounter (18 per participant). These video segments were cropped to the length of time that the drone was visible to the driver (generally 6–12 seconds). Next, researchers drew AOI polygons on individual video frames in a sequence separated by intervals of approximately 5–10 frames. Once the researcher manually situated each AOI, an "anchor" was created within the software. Distance and size differences of the AOIs between these anchors were interpolated by the *ETAnalysis* software to ensure that all fixations and dwells on the AOIs (i.e., drones, operators) were captured.

For each drone encounter, one or two AOIs were drawn (Figure 3.15). For the racing and scanning drones, the drone itself was sufficiently separated from the operators that two AOIs were used, one drawn around the operators and one around the drone itself. Figure 3.15 presents an example video frame that has been coded with two AOIs. At this moment in time, the participant was fixating on a racing drone (yellow box). The other AOI (red box) encompasses the drone operators. This figure also includes heat maps (green-yellow patterns, with yellow indicating higher amount of gaze at that location) for the participant's fixations within the AOIs.

Figure 3.15: Example of a participant fixation pattern for a racing drone (two AOIs)

Drone encounters with the "takeoff" flight pattern did not allow the same AOI coding as the other two flight paths. Because the drone was slowly gaining altitude as the participant passed, the drone was often partially overlapping or directly adjacent to the operators. In these cases, only one AOI was used, which encompassed both the drone and the operators. Figure 3.16 provides a screenshot of the *ETAnalysis* software where the participant is fixating on a takeoff drone encounter and only one AOI (red box) was created.

Once the AOIs were coded for each individual video file, output spreadsheets of all fixations and dwells for each AOI were produced by using the *ETAnalysis* software. Fixations and dwells outside the coded AOIs were universally defined as OUTSIDE and were not analyzed further. Researchers exported these .txt files and imported them into different analysis packages (e.g., Microsoft *Excel* and *RStudio*) for further analysis.

Figure 3.16: Example of a participant fixation pattern for a takeoff drone (one AOI)

3.4.2 Simulator Data

Simulator data were collected from the driving simulator and *SimObserver* platform during the experiment. A complete data file was generated for each participant for each of the four experimental drives. Files, including collected video data and all output of vehicle characteristics (e.g., lateral position and velocity), were opened in the *Data Distillery (Version 1.34)* software suite, which provided quantitative outputs (numerical and graphical) in combination with the recorded video. Figure 3.17 shows the *SimObserver* video output in conjunction with numerical data (right side) and graphical representations of data in columns (bottom).

In the *Data Distillery* program, the 18 drone encounters for each participant were located by using the video data. Velocity and lateral position data from the simulator corresponding to the encounters were segmented to include the 10 seconds before and 5 seconds after each drone encounter, for a total segment of 15 seconds. This time segmentation was chosen to include that time that the drone was visible to the participant and to record any changes in parameters in the approach to the drone. The 5 seconds after the drone encounter were included to see if the parameters shifted again after the participant passed the drone.

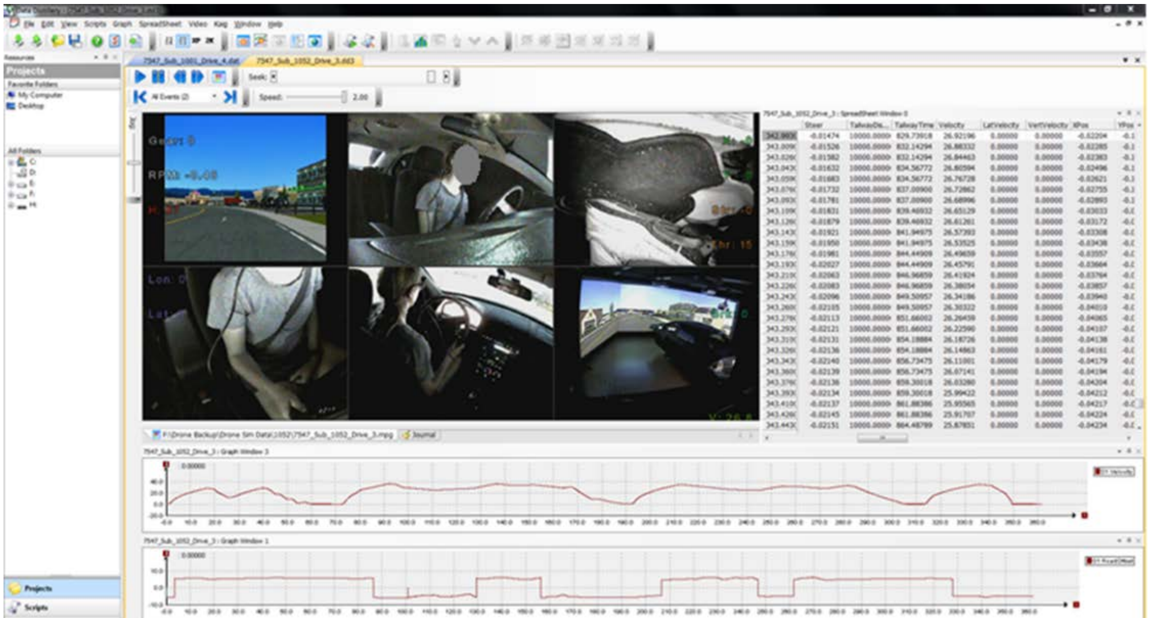


Figure 3.17: Screenshot of *Data Distillery* software interface (identifiable participant information was removed)

4.0 RESULTS

This chapter presents results of the simulator experiment. Section 4.1 describes the participant demographics. Section 4.2 provides the results from the analysis of visual attention. This chapter also highlights selected drone encounters in which individual participants exhibited evidence of distraction based on atypical lane position or speed.

4.1 PARTICIPANTS

Study participants were recruited from the community in and around Corvallis, Oregon.

4.1.1 Summary Statistics

In total, 54 participants (24 women and 30 men) participated in the simulator study. Approximately 24% (7 women and 6 men) of participants reported simulator sickness and did not complete the experiment (Table 4.1). All responses recorded from participants who exhibited simulator sickness were excluded from the analyzed dataset. Failure to calibrate accurately the experimental equipment resulted in loss of data for two additional participants.

Table 4.1: Summary of Participant Population

POPULATION	TOTAL	MEN	WOMEN
Total enrolled	54 (100%)	30 (56%)	24 (44%)
Simulator sickness (%)	13 (24%)	6 (46%)	7 (54%)
Experiment calibration issues (%)	2 (4%)	2 (100%)	0 (0%)
Final analyzed sample (%)	39 (76%)	22 (54%)	17 (46%)

The final analyzed sample population comprised 39 participants who completed the experiment and had complete simulator data, 30 of whom (77%) also had complete eye-tracking data. Participants ranged in age from 18 to 70 years (mean: 28.7 years).

4.1.2 Demographics

Every effort was made to recruit a representative sample of the Oregon driving public. Table summarizes self-reported demographic data of the final sample population. All 39 participants were licensed drivers with residence in the state of Oregon (but not necessarily Oregon-licensed).

Table 4.2: Participant Demographics

QUESTION	POSSIBLE RESPONSES	NUMBER OF PARTICIPANTS	PERCENTAGE OF PARTICIPANTS
How many years have you been licensed?	1–5 years	13	33%
	6–10 years	14	36%
	11–15 years	2	5%
	16–20 years	2	5%
	More than 20 years	7	18%
How often do you drive in a week?	1 time per week	4	10%
	2–4 times per week	5	13%
	5–10 times per week	12	31%
	More than 10 times per week	18	46%
How many miles did you drive last year?	0–5,000 miles	8	21%
	5,000–10,000 miles	12	31%
	10,000–15,000 miles	12	31%
	15,000–20,000 miles	5	13%
	More than 20,000 miles	2	5%
What corrective lenses do you wear while driving?	Glasses[1]	0	0%
	Contacts	10	26%
	None	29	74%
Do you experience motion sickness?	Yes	2	5%
	No	37	95%

[1]Recruitment materials stated that wearing glasses was an exclusionary criterion.

4.1.3 Post-Drive Survey Results

After participants completed the driving simulator portion of the experiment, they were asked to complete a short survey regarding drone operations near roadways. Results of two questions from this survey are reported in Table 4.3. Approximately one-quarter of participants (26%) reported that they had seen a drone while driving in real life. This finding supports the notion that drone operation near roadways is a relevant, current issue. Considering the case of official DOT drone operations located near a roadway, 77% of respondents stated that advanced warning signs would be helpful to warn drivers of approaching drone operations.

Table 4.3: Responses to post-drive survey questions

QUESTION	OPTION	NUMBER OF PARTICIPANTS	PERCENTAGE OF PARTICIPANTS
Before this experiment, had you ever seen a drone while driving?	Yes	10	26%
	No	29	74%
Do you think advanced warning signs would be helpful to you as a driver?	Yes	30	77%
	No	9	23%

One of the research questions concerned whether there was a difference in the distraction potential of drone operations based on the land use of the surrounding environment (rural or urban). In the post-drive survey, participants were asked to indicate whether, in the near future, they expected drone use to be more substantial in a rural or an urban environment, and to provide their reasoning for their choice. Participants indicated that they expected urban environments to have the greatest presence of drone operations in the near future (Figure 4.1). Most participants who chose the "Urban" response cited higher population density as the impetus for more drone operations. Respondents who selected "Suburban" reported that they considered drones to be a recreational toy that would be used by suburban families. Participants who selected "Rural" noted that more space makes drone operations more likely. The lone "Other" response suggested that drone operations would be prevalent everywhere.

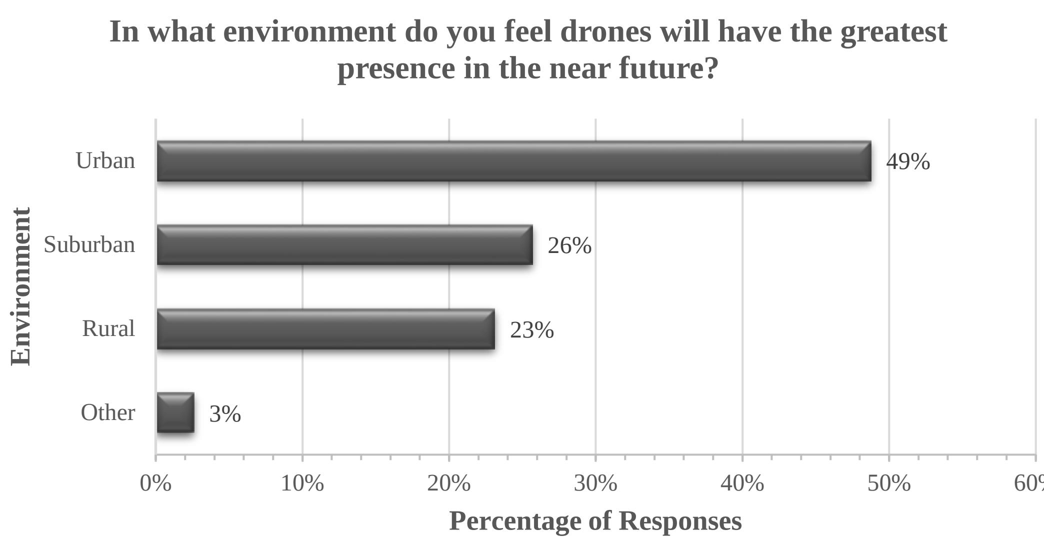


Figure 4.1: Participant perspectives on future drone use

4.2 VISUAL ATTENTION

Visual attention data were gathered and reduced from the ASL Mobile Eye XG for the 30 participants with complete eye-tracking data. This section organizes eye-tracking results by the three independent variables: flight pattern, land use, and lateral offset. Data were analyzed in the statistical software *R Studio* version 1.0.153.

4.2.1 Total Fixation Duration

For each drone encounter, the number and length of participants' fixations on drone operations were recorded. For all drone encounters, a total fixation duration (TFD) was generated by summing all participants' fixations on a drone operation. A TFD of 0 indicates that the participant did not look at the drone operation. A higher TFD indicates greater interest in the operation, suggesting a higher potential for distraction (Poole and Ball 2005). TFD measurements can be useful for comparing the distraction potential of different variables and identifying critical environments and characteristics of distracting drone operations. In the following subsections, the TFD is used as a performance metric to compare the visual distraction potential between the levels of the three independent variables.

4.2.1.1 Flight Pattern

The independent variable "flight pattern" was specified at three levels: takeoff, racing, and scanning. The TFD was calculated for each participant during each drone encounter, and encounters were sorted by flight pattern. Data were visualized as boxplots of TFD disaggregated by flight pattern (Figure 4.2). Median TFDs ranged from 0.570 to 0.615 seconds, with the racing flight pattern having the highest and the scanning flight pattern having the lowest median. The subjects did not fixate on the drone (TFD = 0) in 31% of takeoff exposures, 29% of racing exposures, and 28% of scanning exposures.

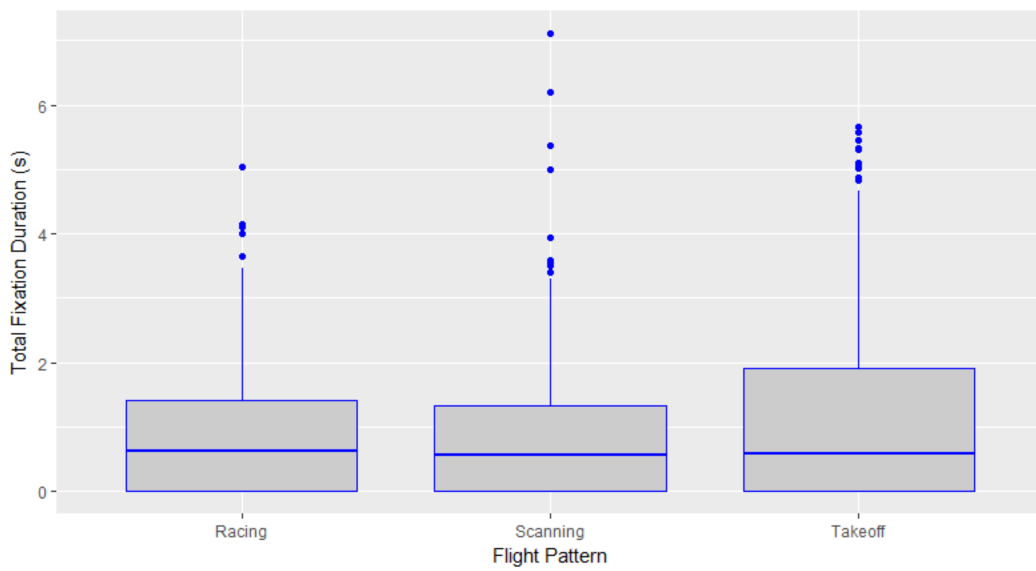


Figure 4.2: Boxplots of TFD disaggregated by flight pattern

Table 4.4 contains descriptive statistics for the TFDs of participants for each type of flight pattern of the data set with the zeros removed. TFD distributions on the drone operations were strongly skewed to the right. Data were log-transformed, and zero values (i.e., data for participants who did not look at the drone operation) were removed from the analysis. Therefore, the statistical test represents the subgroup of drone encounters where the driver looked at the drone operation. One-way ANOVA F-test, conducted to determine whether the log average total fixation duration (ATFD) differed between the three flight paths, showed that the effect of flight pattern on the log ATFD was not statistically significant ($F(2, 377) = 1.02$, $p = 0.362$).

Table 4.4: Descriptive Statistics for TFD by Flight Pattern

FLIGHT PATTERN	COUNT	MEAN (s)	SD (s)	95% CI		MIN (s)	MAX (s)
				LOWER	UPPER		
Racing	180	0.926	1.07	0.768	1.08	0	5.04
Scanning	180	0.974	1.21	0.796	1.15	0	7.11
Takeoff	180	1.21	1.51	0.989	1.43	0	5.65

4.2.1.2 Land use

The independent variable "land use" was specified at two levels: rural and urban. The TFD was calculated for each participant during each drone encounter, and encounters were sorted by land use. Data were visualized as boxplots of TFD disaggregated by land use (Figure 4.3). Median TFDs were 0.800 seconds for rural and 0.415 seconds for urban land use. The subjects did not fixate on the drone (TFD = 0) in 22% of rural exposures and 37% of urban exposures, indicating that subjects were less likely to see the drone in the urban environment.

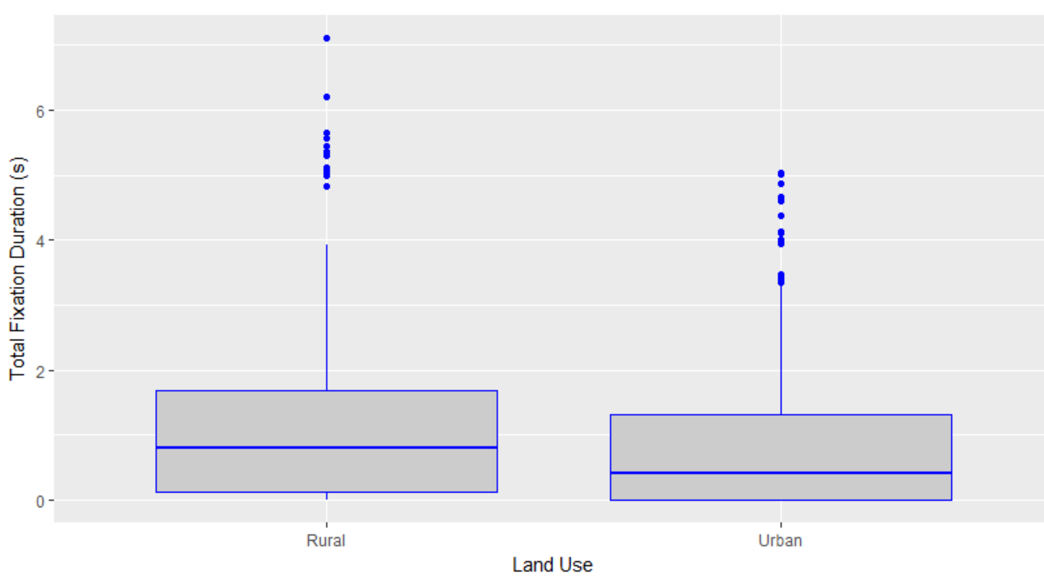


Figure 4.3: Boxplots of TFD disaggregated by land use

Table 4.5 contains descriptive statistics for the TFDs with each land use. TFD distributions on the drone operations were strongly skewed to the right. Data were log-transformed, and zero values (i.e., data for participants who did not look at the drone operation) were removed from the analysis. Therefore, the statistical test represents the subgroup of drone encounters where the driver looked at the drone operation. Welch's t-test, conducted to determine if the log ATFD differed between the two land uses, revealed no significant difference in log ATFD between rural (log mean = 0.998 seconds) and urban (log mean = 0.970 seconds) land uses (t (364) = 0.627, p = 0.53).

Table 4.5: Descriptive Statistics for AFD by Land Use

LANDUSE	COUNT	MEAN (s)	SD (s)	95% CI		MIN (s)	MAX (s)
				LOWER	UPPER		
Rural	270	1.20	1.38	1.03	1.36	0	7.11
Urban	270	0.878	1.16	0.739	1.02	0	5.04

4.2.1.3 Lateral Offset

The independent variable "lateral offset" was specified at three levels: 0, 25, and 50 ft. The TFD was calculated for each participant during each drone encounter, and encounters were sorted by lateral offset. Data were visualized as boxplots of TFD disaggregated by lateral offset (Figure 4.4). Median TFDs ranged from 1.18 to 0.215 seconds, with the 0-ft offset having the highest and the 50-ft offset having the lowest median. The subjects did not fixate on the drone (TFD = 0) in 16% of 0-ft offset exposures, 28% of 25-ft offset exposures, and 44% of 50-ft offset exposures, indicating that subjects were more likely to see the drone operations with smaller lateral offsets.

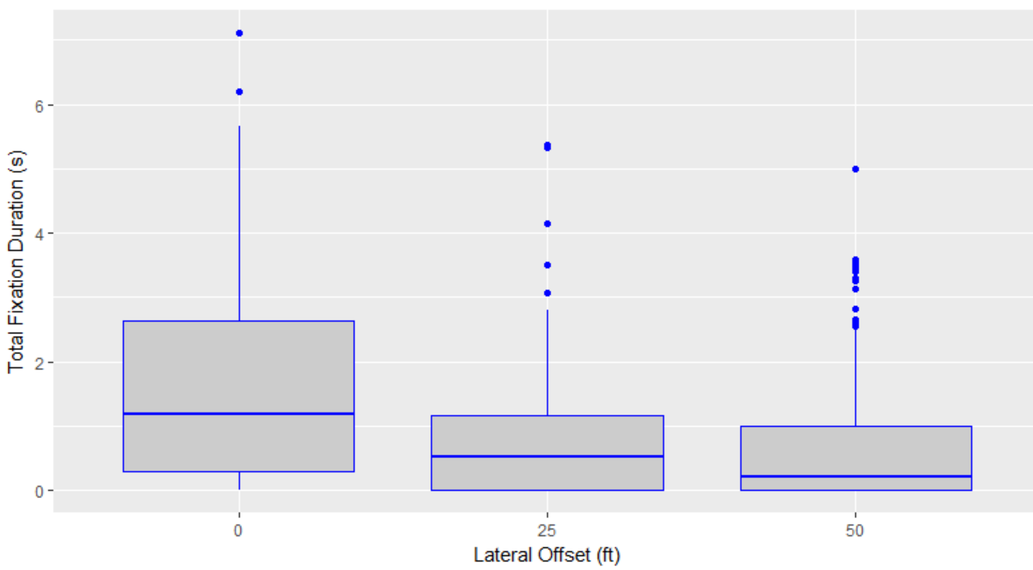


Figure 4.4: Boxplots of TFD disaggregated by lateral offset

Table 4.6 contains descriptive statistics for the TFDs of participants for each lateral offset condition. TFD distributions on the drone operations were strongly skewed to the right. Data were log-transformed, and zero values (i.e., data for participants who did not look at the drone operation) were removed from the analysis. Therefore, the statistical test represents the subgroup of drone encounters where the driver looked at the drone operation. One-way ANOVA F-test, used to determine whether the log ATFD differed between levels of lateral offset, revealed a significant effect of lateral offset on the log ATFD ($F(2, 377) = 11.55$, $p < 0.001$). A Tukey HSD post hoc pairwise comparison was performed to determine where differences between group means occurred. Results at a 95% confidence level (Table 4.7) showed a significant difference between ATFDs of the 0-ft and 25-ft offsets, and between ATFDs of the 0-ft and 50-ft offsets, but no significant difference between ATFDs of the 25-ft and 50-ft offsets.

Table 4.6 Descriptive Statistics for TFD by Lateral Offset

LATERAL OFFSET	COUNT	MEAN (s)	SD (s)	95% CI		MIN (s)	MAX (s)
				LOWER	UPPER		
0 ft	180	1.63	1.59	1.40	1.87	0	7.11
25 ft	180	0.805	0.964	0.663	0.946	0	5.36
50 ft	180	0.676	0.972	0.533	0.819	0	5.00

Table 4.7: Results of Tukey HSD Test for Log TFD

COMPARISON	MEAN DIFFERENCE	*P*	95% CI	
			LOWER	UPPER
0-ft vs. 25-ft offset	0.224	<0.001	0.105	0.342
0-ft vs. 50-ft offset	0.194	0.001	0.067	0.322
25-ft vs. 50-ft offset	0.029	0.860	-0.103	0.161

4.2.2 Dwell Duration

In addition to fixations, dwells provide another representation of visual attention. Dwells are the amount of uninterrupted time that a participant looks at an AOI. The sum of the durations of all fixations and saccades that occur consecutively within an AOI constitutes one dwell (Bergstrom and Schall 2014). Dwell durations are particularly useful data because they can be used as a surrogate safety measure to predict crash risk. The 100-Car Naturalistic Driving Study at Virginia Tech found that a total eyes-off-road glance of greater than 2 seconds at least doubles a driver's near-crash/crash risk (Klauer et al. 2006). For this study, a dwell on a drone operation with a duration of more than 2 seconds was considered to indicate a "high-risk" dwell.

This section will investigate dwell durations of greater than 2 seconds to determine potential safety concerns with drone operations at various lateral offsets from the roadside. Data were visualized as boxplots of individual dwell times disaggregated by lateral offset (Figure 4.5), with high-risk dwells (duration > 2 seconds) shown above the red horizontal line.

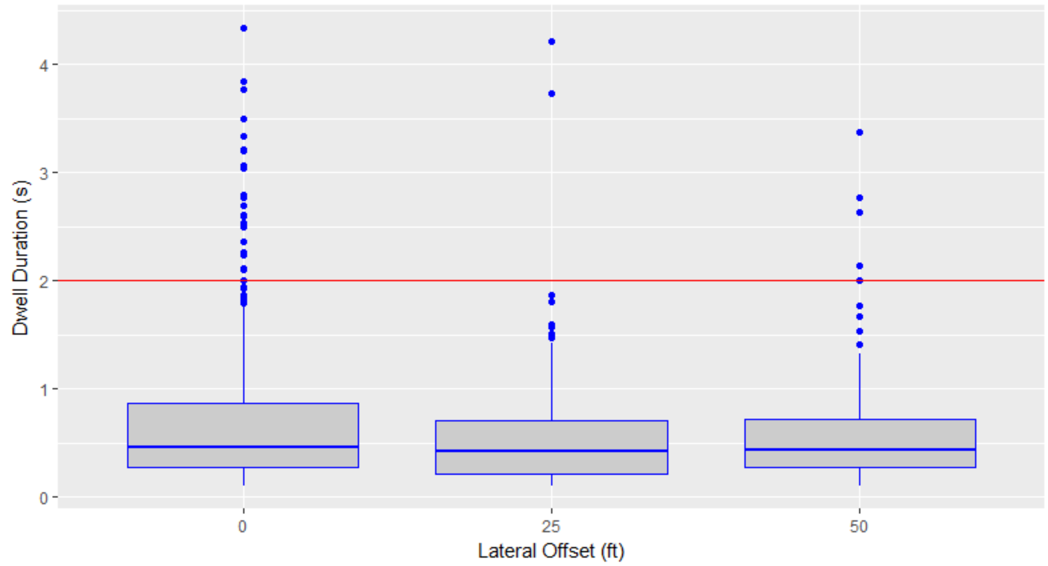


Figure 4.5: Boxplots of dwell duration disaggregated by lateral offset

In total, there were 1,046 individual dwells across 540 drone encounters (18 drone encounters for 30 participants). Of the 33 high-risk dwells, 25 occurred in the 0-ft offset, three occurred in the 25-ft offset, and five occurred in the 50-ft offset. The results suggest that drone operations located immediately adjacent to the roadside (0-ft lateral offset) offer the greatest distraction potential. The other two offsets had much smaller, but extant, potentials for generating unsafe glances away from the roadway toward a drone operation.

4.2.3 Drones and Operators

For this experiment, a drone operation was defined as a single quadcopter drone flying near two human operators. There is the potential that the drone and/or the operator pair will result in a distraction. To determine whether the drone or operators result in a higher potential for distraction, the TFD was calculated for the drone and the operators separately. This comparison was conducted for the scanning and racing flight patterns, because only one AOI was coded for the takeoff flight pattern due to proximity of the drone to the operators. Data were visualized as boxplots of TFD disaggregated by character (Figure 4.6). Median TFDs were 0.13 seconds for the drone and 0.27 seconds for the operators. Table 4.8 provides the descriptive statistics for the TFDs of the participants on the drones and operators.

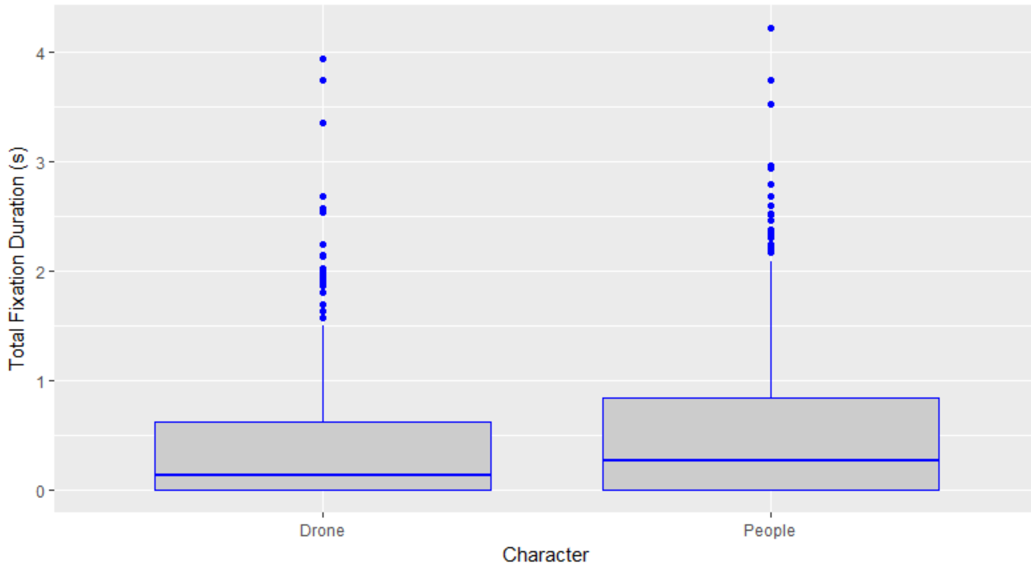


Figure 4.6: Boxplots of TFD disaggregated by character

Table 4.8 provides the descriptive statistics for the TFDs of the participants on the drones and operators. TFD distributions on the drone operations were strongly skewed to the right. Data were log-transformed, and zero values (i.e., data for participants who did not look at the drone operation) were removed from the analysis. Therefore, the statistical test represents the subgroup of drone encounters where the driver looked at the drone operation. Welch's t-test, used to determine whether the log ATFD differed between the characters, showed that the log ATFD for the drone (log mean = 0.719 seconds) was significantly less than the log ATFD for the operators (log mean = 0.843 seconds) (t (328) = -2.88, p = 0.004). These results indicate that the operators may result in a higher potential for distraction than the drones themselves.

Table 4.8: Descriptive Statistics for TFD by Character

CHARACTER	COUNT	MEAN (s)	SD (s)	95% CI		MIN (s)	MAX (s)
				LOWER	UPPER		
Drone	300	0.415	0.656	0.340	0.489	0	3.94
Operators	299	0.578	0.783	0.489	0.667	0	4.22

4.2.4 Visual Attention Selected Event

Video data collected through the *SimObserver* platform provide different information on participant behavior than can be measured with sensors. This information can help with the interpretation of sensor data, such as by highlighting particularly risky glances toward drone events. For example, one participant leaned forward over the steering wheel to get a better look at the drone (Figure 4.7), demonstrating that the drone operation was an important visual distraction for them. In this particular case, the drone was in a scanning pattern at a 25-ft offset in the rural environment. The participant's head was turned to the side for 2.9 seconds. The physical act of leaning over the steering wheel and turning to look at the drone operation is a risky, distracted behavior. After this participant had finished the drive portion of the experiment, the participant noted to the researcher that they had thought the operators were either bird watching or kite flying before figuring out that they were operating a drone.

Figure 4.7: Example of participant leaning over the steering wheel to look at a drone operation. Top left: Simulated scene as projected on the screen. Top right: Driver leaning over the steering wheel. Bottom left: View of the driver's torso leaning forward. Bottom right: Driver turning his head to the look at the drone operation.

4.3 LANE POSITION AND VELOCITY

The driving simulator collects data related to participants' lane position and velocity throughout the entire simulation. To observe participants' behavior in terms of these metrics for the drone encounters, data were segmented so that only the 10 seconds before and 5 seconds after the drone encounter were observed. The 10-second interval before the encounter was chosen to encompass the general period when the drone operation was visible to the driver. The 5-second period after was chosen to observe if any impacts lasted beyond the drone encounter.

Profiles of these data for all of the subjects were plotted to visualize driver behavior around drone encounters. Figure 4.8 shows an example lane position profile for all 39 participants for one drone encounter (50-ft lateral offset, racing flight pattern, and rural land use), where each line tracks the centroid of the participant's vehicle. Figure 4.9 provides the speed profile for this same drone encounter.

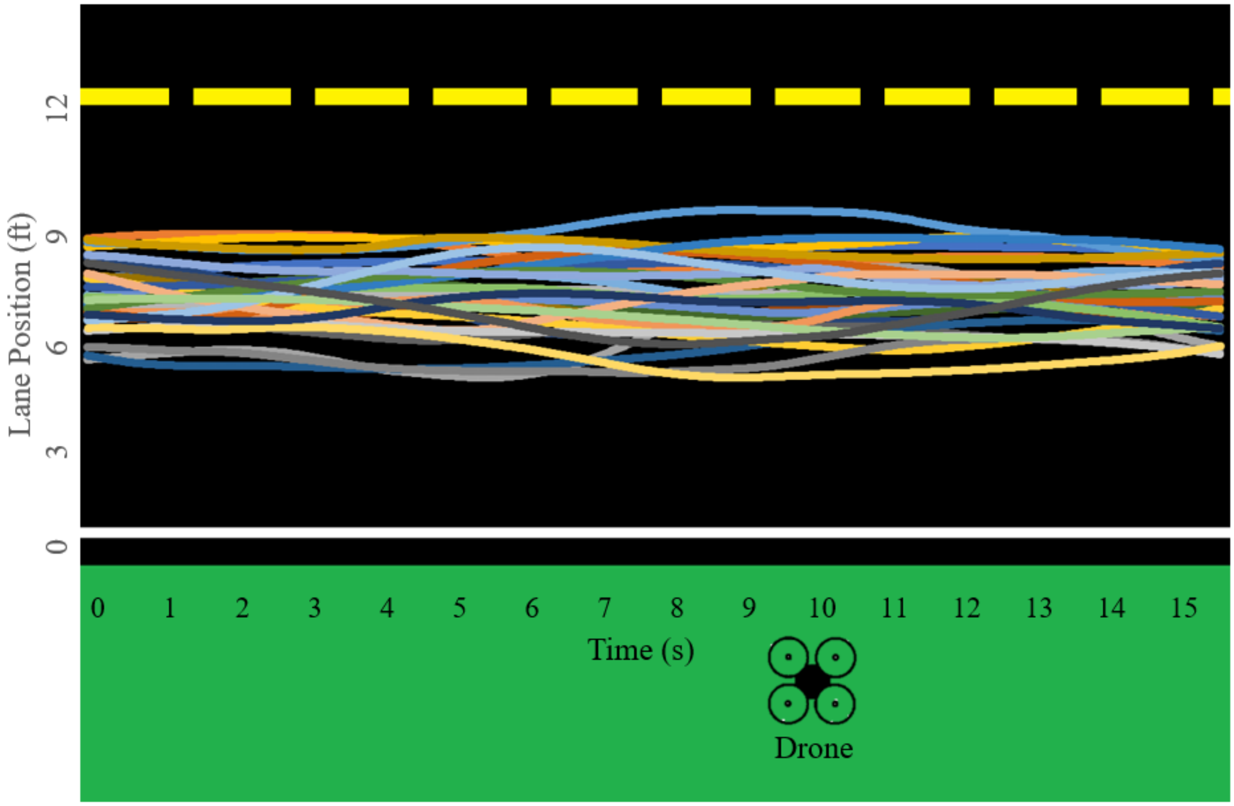


Figure 4.8: Lane position of 39 participants passing a drone occurring at 10 seconds

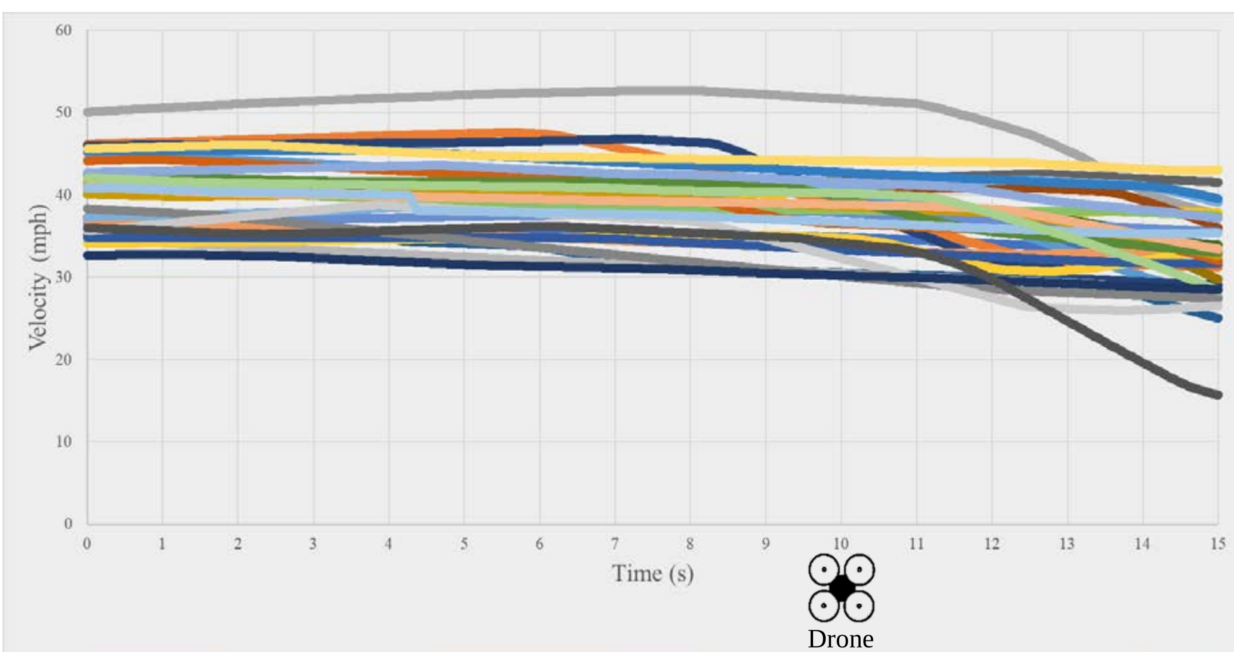


Figure 4.9: Speed profile of 39 participants passing a drone occurring at 10 seconds

During the data reduction process, it was discovered that geometric alignment of the roadway had a major effect on many of the lane position and velocity profiles near drone encounters, making aggregate statistical analysis invalid. However, across all drone operations, the lane positions and velocities of certain participants showed important shifts near certain drone encounters. All of the lane position and speed profiles were visually inspected to identify any important effects in close proximity to a drone operation. The following sections describe selected drone encounter events where particularly unsafe lane and speed deviations occurred.

4.3.1 Lane Position of Selected Events

During the process of reducing the lane position data, it was found that some drone encounters resulted in at least a portion of the participant's vehicle crossing into another lane. The combination of looking at the drone operation while simultaneously crossing into the adjacent lane was considered to be a risky behavior.

Table 4.10 summarizes all of the unique drone encounters in which a participant crossed into another lane, either partially or fully, in close proximity to the drone operation. Two general types of lane crossing were observed. In *distracted lane encroachment*, the participant looked at the drone operation, was not paying attention to the road, and, as a result, their vehicle drifted partially into the adjacent lane. In *intentional lane encroachment*, the presence of the drone operation near the roadside made the driver uncomfortable such that they intentionally shifted their vehicle (at least partially) into the adjacent lane to give the drone operation wider berth. For a full description of the potentially unsafe events, the table includes other associated variables, such as the distance the vehicle travelled into the adjacent lane, the TFD on the drone operation, and the vehicle's change in velocity. In two cases (events 3 and 4, and events 6 and 7), the same participant crossed into another lane for two separate drone events.

Table 4.9: Summary of Unique Drone Encounters in which the Participant's Vehicle Crossed at Least Partially Into the Adjacent Lane

EVENT	DRONE ENCOUNTER			DISTRACTED/ INTENTIONAL LANE SHIFT	ADJACENT LANE INTRUSION (ft)	TFD (s)	VELOCITY (mph)
	LATERAL OFFSET	LAND USE	FLIGHT PATTERN				
1	0 ft	Rural	Takeoff	Intentional	0.22	0.20	2.2
2	0 ft	Rural	Takeoff	Intentional	1.04	5.65	2.7
3	0 ft	Rural	Racing	Distracted	0.48	3.64	-3.2
4	0 ft	Rural	Takeoff	Distracted	3.65	1.64	0.5
5	0 ft	Rural	Takeoff	Intentional	0.68	0.91	1.2
6	0 ft	Rural	Racing	Intentional	0.61	0.00	1.7
7	0 ft	Rural	Takeoff	Intentional	1.38	0.57	0.6
8	0 ft	Rural	Takeoff	Distracted	0.25	3.29	4.1
9	25 ft	Rural	Scanning	Distracted	0.48	0.00	1.4
10	25 ft	Rural	Scanning	Distracted	0.48	1.35	5.3

Of the 10 lane crossings, 8 crossings (80%) were located at the 0-ft lateral offset. All 10 crossings (100%) occurred in the rural land use environment (Table 4.10).

Figure 4.10 provides an example of an intentional lane encroachment, in which the participant has seen the drone operation and has shifted approximately half of their vehicle into the oncoming lane. Figure 4.11 provides an example of a distracted lane encroachment, in which the participant has turned their head to the right to look at the drone operation and their vehicle has moved slightly into the oncoming lane.

Figure 4.10: Example of an intentional crossing of the centerline away from a 0-ft offset drone operation

Figure 4.11: Example of a distracted drift into the adjacent lane, in which the participant turned their head to look at the drone operation

4.3.2 Velocity of Selected Events

Data were analyzed to identify drone encounters in which the participant had a significant change in their velocity in response to the drone encounter. For example, Figure 4.12 shows the speed profiles for all 39 participants for a single drone encounter (0-ft lateral offset, takeoff flight pattern, and rural land use). One participant (in blue) seemed to slow down significantly when passing the drone operation. Similar events across all speed profiles were collected and matched with the visual attention data to determine if the speed reduction was likely in response to seeing the drone operation. Table 4.11 summarizes the three events where a significant speed reduction was thought to be in reaction to seeing the drone operation.

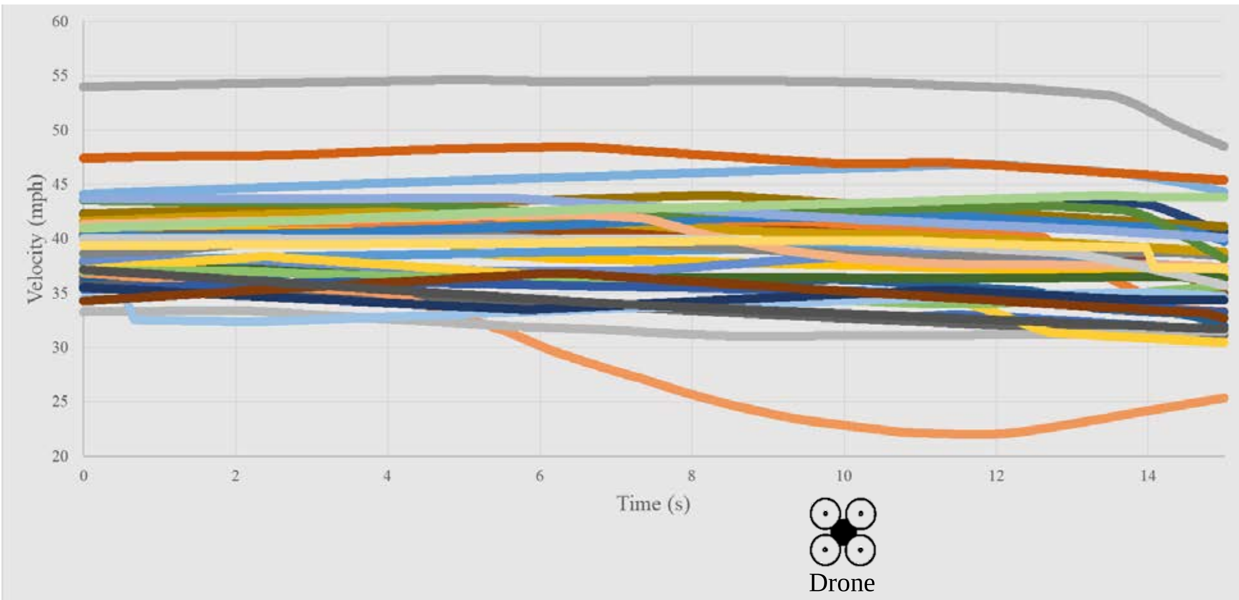


Figure 4.12: Speed profile of 39 participants passing a drone occurring at 10 seconds

Table 4.10: Summary of Unique Drone Encounters in which the Participant's Vehicle Markedly Changed Velocity in Reaction to a Drone Operation

EVENT	DRONE ENCOUNTER			VELOCITY (mph)	TFD (s)	LANE POSITION (+ TOWARD DRONE)
	LATERAL OFFSET	LAND USE	FLIGHT PATTERN			
1	0	Urban	Takeoff	-7.2	4.66	-0.1 ft
2	0	Rural	Takeoff	-14.0	3.81	0.3 ft
3	0	Rural	Scanning	-10.7	1.51	0.2 ft

All three events occurred when the drone operation was located immediately adjacent to the roadside (0-ft lateral offset). Two of the three events occurred in the rural land use environment. The reductions in velocity were meaningful, averaging 10.6 mph.

5.0 CONCLUSIONS

This chapter presents study conclusions related to the distraction potential of drone operations near roadway infrastructure. The first section summarizes the major findings of the experiment. The following sections discuss the limitations of this study and opportunities for future research related to drone distraction.

5.1 FINDINGS

The results of this study demonstrate a consistent narrative related to how drivers are distracted by drones operating near roadways. Overall, the results show that drone operations do pose a potential distraction, and this potential varies based on the characteristics of the environment in which the drone is flown. There may be an increased risk of a crash associated with drone operations up to at least 50 ft from the roadside. In more detail, the following are the primary findings of this study:

- The frequency and length of glances at drone operations, as determined by the TFD and dwell duration, increased the closer the drone operation was to the roadway. The mean AFD was statistically higher for the 0-ft than for the 25-ft or 50-ft lateral offset, and a larger number of high-risk (>2 second) dwells occurred at the 0-ft offset. Unsafe behaviors, such as crossing into an adjacent lane or sharply decreasing speed, were observed when the drone operation was at a 0-ft offset. These results suggest that drone operations are more distracting the closer they are to the roadway.

- Drone operations appear to be more distracting in rural environments. The unsafe behavior of crossing into an adjacent lane in response to a drone operation was only observed in the rural environment. A possible explanation for the increased distraction in rural environments may be that there is less visual clutter present, and that the drone operations are more prominent as compared to the urban environment.

- There is no consistent pattern in visual attention (as measured by TFD) for the three different flight patterns studied in this experiment: scanning, racing, and takeoff. The general characteristics of a drone operation, including the presence of a drone and operators, seem to present the same distraction potential regardless of the specific flight pattern of the drone.

- There is a potential for unsafe (>2 seconds) glances at all three lateral offsets: 0, 25, and 50 ft. Previous research determined that eyes-off-road glances lasting more than 2 seconds double the risk of a near-crash/crash events (Klauer et al. 2006). A significantly larger number of unsafe glances occurred at the 0-ft offset. This finding suggests that the closer the drone operation is to the roadside, the greater the potential distraction and the higher the safety risk will be. A drone operation set at 25 or 50 ft from the roadside would likely have a lower risk than a drone operation at a 0-ft lateral offset (although a few unsafe glances still occurred at the furthest lateral offset of 50 ft). For policymakers, a 50-ft offset for drone operations would be the lowest risk based on the offsets considered in this study. A factor of safety beyond this distance may also be warranted.

- Drivers have the potential to be distracted by both drones and their operators near roadways. Both characters individually generated off-road glances, with the ATFD on the operators being slightly higher than the ATFD on the drone. FAA policies recommend the use of two operators within line-of-sight for drone flights conducted under Part 107 procedures (FAA 2016d). ODOT's Unmanned Aircraft Systems programs, policies, and procedures document require a pilot in command and a visual observer for all drone operations (Singh 2017). Therefore, the drone operations in this experiment consisted of a quadcopter drone and two operators nearby.

5.2 LIMITATIONS

Although many questions regarding drones have been explored by this first-of-its-kind study, interpretation of the results should take into consideration the limitations of the current work. These limitations point to future research opportunities in the space of drone and driver interactions. The following are the primary limitations of this project:

- A basic limitation of within-subject design is fatigue effects, which can cause a participant's performance to degrade over the course of the experiment as they become tired or bored. The order of the scenarios was partially randomized to limit the effect of these fatigue effects.

- Geometric alignments of the tracks and the location of the curves in the roadway limited the interpretation of the velocity and lateral position data. Although valuable results were extracted from these measurements in individual instances, the variability between drone encounters made aggregate statistical analyses of the velocity and lateral position information impossible.

- The resource and time constraints of the project limited the number and levels of variables that could be evaluated. In particular, the lateral offset was only analyzed up to a distance of 50 ft. Distraction potential beyond this distance cannot be determined from these experimental results.

5.3 FUTURE WORK

Additional research is needed to continue to explore the emerging safety issue of drone operations near roadways and to extend the work of this study. The following are potential research threads that would augment this study and further expand the topic of how drivers are distracted by drones operating near roadways:

- Studies with lateral offsets beyond 50 ft would provide a more thorough understanding of where drone operations no longer increase risk to drivers. This research only studied lateral offsets up to 50 ft and found that there is the potential for high-risk glances at drone operations at 50 ft.

- This research studied land use, lateral offset, and flight pattern as the independent variables for the drone operation characteristics. Many other variables could also be considered. For example, drones fly at various heights above the ground for different applications. A study that examines the potential distraction of drone operations based on the flying height would add to the conclusions from this study and provide a more robust exploration of drone operations near roadways.

- Seventy-seven percent of the participants in this study responded that warning signage to alert drivers of DOT drone operations near the roadway would be helpful to them as a driver. Additional studies to determine when signs might be used, what types of signs are most beneficial, and where the signs should be placed relative to drone operation would be beneficial to state DOTs and other transportation policymakers.

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APPENDIX A

Institutional Review Board Approval Notice

Human Research Protection Program
Institutional Review Board
Office of Research Integrity
B308 Kerr Administration Building, Corvallis, Oregon 97331-2140
(541) 737-8008
IRB@oregonstate.edu | http://research.oregonstate.edu/irb

APPROVAL NOTICE

Date of Notification	04/13/2017	Date Approved	04/07/2017
Principal Investigator	David Hurwitz	Study ID	7547
Study Title	Driver Distraction Due to Drones		
Study Team Members	Masoud Abadi, Zachary Barlow, Kamilah Buker, Cadell Chand, Kayla Fleskes, Dylan Horne, Hisham Jashami, Hameed Mohammed, Michael Olsen, Logan Scott-Deeter		
Review Level	Expedited	Category(ies)	6, 7
Submission Type	Project Revision		
Waiver(s)	None		
Risk Level for Children	N/A		
Number of Participants	100 Do not exceed this number without prior approval		
Funding Source	Oregon Department of Transportation	PI on Funding	David Hurwitz
Proposal #	31167	Cayuse #	16-1942

The above referenced study was reviewed and approved by the OSU Institutional Review Board (IRB).

EXPIRATION DATE: 07/18/2019

Continuing review applications are due at least 30 days prior to expiration date

Comments: In this project revision, protocol is updated to be consistent with the approved consent form (to include the use of video cameras). New personnel are added and the survey and consent form have been revised to add post driving questions.

Please note when applicable, if the PI has not already done so, the HRPP staff will update the version date on the protocol and consent document(s).

This study has been determined to meet the **FLEX** criteria and the following apply:

☒ Approval period has been extended beyond one year, but not greater than three years
☐ Reasonable safeguard standard regarding the requirement for parental permission
☐ Reasonable safeguard standard regarding the enrollment of pregnant women

Adding any of the following elements will invalidate the FLEX determination and require the submission of a project revision:

- Increase in risk
- Federal funding or a plan for future federal sponsorship (e.g., proof of concept studies for federal RFPs, pilot studies intended to support a federal grant application, training and program project grants, no-cost extensions)
- Research funded or otherwise regulated by a federal agency that has signed on to the Common Rule, including all agencies within the Department of Health and Human Services
- FDA-regulated research

- NIH-issued or pending Certificate of Confidentiality
- Prisoners or parolees as subjects
- Contractual obligations or restrictions that require the application of the Common Rule or which require annual review by an IRB
- Classified research
- Clinical interventions

Principal Investigator responsibilities for fulfilling the requirements of approval:

- All study team members should be kept informed of the status of the research.
- Any changes to the research must be submitted for review and approval prior to the activation of the changes. **This includes, but is not limited to, increasing the number of subjects to be enrolled.** Failure to adhere to the approved protocol can result in study suspension or termination and data stemming from protocol deviations cannot be represented as having IRB Approval.
- Reports of unanticipated problems involving risks to participants or others must be submitted to the HRPP office within three calendar days.
- Only consent forms with a valid approval stamp may be presented to participants.
- Submit a continuing review application or final report to the HRPP office for review at least four weeks prior to the expiration date. Failure to submit a continuing review application prior to the expiration date will result in termination of the research and discontinuation of enrolled participants.

APPENDIX B

Approved Informed Consent Document

Human Research
Protection Program
Oregon State University
Study # 7547
Current Approval: 04/07/2017
Do not use after: 07/18/2019
Approved

CONSENT FORM

Project Title:	Driver Distraction Due to Drones
Principal Investigator:	Dr. David Hurwitz
Student Researcher:	Zachary Barlow
Co-Investigator(s):	Dr. Michael Olsen
Sponsor:	Oregon Department of Transportation
Version Date:	04/07/2017

1. WHAT IS THE PURPOSE OF THIS FORM?

Welcome to the Oregon State Driving Simulator Laboratory. This form contains information you will need to help you decide whether to be in this research study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS RESEARCH STUDY BEING DONE?

The goal of the research is to Determine the distances in which unmanned aerial vehicles (UAVs) operated around highway corridors become a visual and/or cognitive distraction degrading driving performance, and investigate the potential for distraction across the functional classification of roadways and the density of development adjacent to the roadway.

This research is intended to produce an MS Thesis, peer reviewed publications, and presentations.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a fully licensed driver who has been driving for at least one year and you do not wear glasses (contacts are allowed). You must be between the ages of 18 and 75.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

You will be asked to provide simple information about yourself at the start of the experiment. You then will participate in the driving experiment where you will be seated as the driver in the driver simulator, an actual car atop a motion base (see image to right). You will be asked to navigate a predetermined course across a series of different roadway types while operating the vehicle in as natural a manner as possible.

In addition, before you begin driving, you will be fitted with an optical device (like goggles) and complete a calibration process (adjust glasses for accuracy). During the process you will be asked to look at specific points displayed in the screen in front of you. Once this process is completed you can then look freely anywhere in a scenario as you try to drive the car. However, once the glasses have been secured and adjusted, please do not take off or remove the glasses.

In order for you to get used to the optical device and the driving simulator, you will be given a practice drive. Next, you will be given the experimental drives. Following the experimental drives, you will be given a short post-drive survey with questions related to your experience in the simulator.

Study duration: This study will consist of a 5 minute survey followed by approximately 30 minutes of driving time. After the driving time, there will be a short 10 minute post-drive survey.

Recordings and photographs: Cameras are installed inside the vehicle to capture the driver's response under certain conditions. **If you do not wish to be recorded, you should not enroll as a part of this study.**

Storage and Future use of data: Because it is not possible for us to know what studies may be a part of our future work, we ask that you give permission now for us to use your personal information without being contacted about each future study. Future use of your information will be limited to studies about driver behavior. We will be destroying all identifying information after the completion of data collection.

______You may store my {information} for use in future studies.
Initials

______ You may not store my {information} for use in future studies.
Initials

Future contact: We may contact you in the future for another similar study. You may ask us to stop contacting you at any time.

Study Results: The results of the study will be made available through Oregon State University at the completion of the study.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

There are no known risks that occur when using the eye-tracking equipment. There is a possible risk to you when you operate the driving simulator. Approximately 10-30% of participants who drive the simulator may experience feelings of nausea or actual nausea. If this occurs you may do one of two things:

1.) You have the ability to instantly end the experiment at the sign of any discomfort by depressing the red "emergency stop" button next to the driver's seat in the vehicle, or you should inform the experimenter at any point you feel any discomfort and we will stop the simulation immediately, which should quickly reduce the discomfort. **Moreover, if you already experience any motion sickness while in a real car or the cabin of any other moving vehicle, you should not participate in the experiment.**

There is a risk that we could accidentally disclose information that identifies you. To prevent this, throughout the entire study any information related to the participants will be kept under double lock security. Also, each participant will be randomly assigned a number to remove any identifiable information from the data.

6. WHAT ARE THE BENEFITS OF THIS STUDY?

This study is not designed to benefit you directly. However, your participation may contribute to a better understanding of driver behavior. This will allow engineers to make better assumptions regarding human behavior when designing transportation infrastructure.

7. WILL I BE PAID FOR BEING IN THIS STUDY?

You will be paid $20 for being in this research study.

8. WHO IS PAYING FOR THIS STUDY?

The Oregon Department of Transportation (ODOT) is paying for this research to be done.

9. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you. De-identified data may be shared with other institutions.

If the results of this project are published your identity will not be made public.

To help ensure confidentiality, we will use subject codes, rather than names, to identify any data collected during your simulation drive or any verbal response that you give. The subject codes will be secured in the OSU Driving Simulator Office. Hard copies of the data will be stored behind two locks, while digital copies of the data will be stored on a password protected hard drive. The data will only be accessible by Dr. David S. Hurwitz and student researchers.

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Do not use after: 07/18/2019
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10. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

11. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact: David S. Hurwitz, Associate Professor, School of Civil and Construction Engineering at (541) 737-9242 or by email at david.hurwitz@oregonstate.edu.

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

12. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: 07/18/2019

Participant's Name (printed): ____

____ ______________________________
(Signature of Participant) (Date)

____ ______________________________
(Signature of Person Obtaining Consent) (Date)

APPENDIX C

GLOSSARY

This glossary contains the definitions of abbreviations, acronyms, and common terms.

Table C.1: Definitions of abbreviations and acronyms

Acronym/Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
COA	Certificate of Authorization
DOT	Department of Transportation
FAA	Federal Aviation Administration
IRB	Institutional Review Board
NAS	National Airspace System
NCSL	National Conference of State Legislatures
NHTSA	National Highway Traffic Safety Administration
ODOT	Oregon Department of Transportation
OSU	Oregon State University
TSA	Transportation Safety Administration
UAS	Unmanned Aerial System
sUAS	Small Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UAVSA	Unmanned Aerial Vehicle Systems Association

Table C.2: Definitions of common terminology in the report

Term	Definition
Drone	**Report Definition:** An unmanned aircraft operated remotely by a pilot on the ground that qualifies under the FAA's definition of a sUAS and can be used for commercial or recreational purposes
Drone/UAS	**FAA Definition:** An unmanned aircraft and associated elements (including communication links and components that control the unmanned aircraft) that are required for the pilot to operate safely and efficiently in the national airspace system
sUAS	A specific subset of UAS where the aircraft weighs > 0.55 lb and < 55 lb