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Policy processes and recommendations for Unmanned Aerial System operations near roadways based on visual attention of drivers

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ABSTRACT

Unmanned Aerial Systems (UASs), commonly known as drones, are a rapidly emerging technology with many applications across various commercial, government, and recreational users. Many of these applications have the potential to interact with roadway infrastructure, resulting in potentially risky conflicts between UAS operations and drivers on the roadway. In the United States, policy regulating UAS operations exists at the federal, state, and local levels, but there is little to no regulation specifically related to UAS operations near roadways. The purpose of this study was to evaluate if UAS operations near roadways pose a safety concern by determining if the operations visually distract drivers. In addition, this study sought to develop data-driven policy recommendations to improve the safety of drivers and UAS operators near roadways. To understand how UAS operations near roadways influence the visual attention of drivers, an experiment was designed and conducted in a high-fidelity driving simulator. Thirty participants completed the experiment in the driving simulator and their visual attention was recorded. Analysis of the visual attention results showed that UAS operations draw more visual attention from drivers when they are directly adjacent to the roadside or in a rural environment. Based on the results, a recommended policy to improve safety of UASs for operators and drivers would be to, at a minimum, restrict UAS operations within 7.6 m (25 ft) of the edge of a lane. A procedural overview for implementing legal and effective UAS policy in the United States was developed to navigate the complexities of the evolving UAS policy landscape.

1. Introduction

Unmanned Aerial Systems (UASs), commonly referred to as drones, are a century-old technology that have been recently re-invented such that they are now more usable and affordable for individuals and businesses. UASs consist of the flight vehicle, a payload (e.g., sensors or cameras), and a ground control system (Elias, 2016). The most common UASs, which are exclusively the type discussed in this paper, weigh less than 55 lbs and are often referred to as small UAS (sUAS) vehicles.

In 2015, the Federal Aviation Administration (FAA) began requiring that UAS vehicles for recreational (hobby) and commercial activities be registered. By January 2018, the FAA announced it had registered its 1 millionth UAS (USDOT, 2018). The rise in use of UASs is due to the increasing demand for UASs across a rapidly expanding breadth of applications. For commercial operations, UASs are used in industrial inspection, agriculture, insurance, real estate, aerial photography, and government applications (Schaufele, 2016).

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As the prevalence and applications of UASs have increased, safety concerns have also arisen. Many of these concerns relate to privacy, weaponization, or aircraft collisions (Clarke and Bennett Moses, 2014; Fulton et al., 2009; Schlag, 2013). These concerns have led to policy implementation at the federal, state, and local levels in the United States. However, as is often the case with emerging technologies, there are still safety concerns related to UAS applications that have yet to be addressed by policy makers.

Roadway transportation is a sector that currently implements UAS technology and has the potential to expand their use dramatically. Uses for UASs near roadway transportation and infrastructure include structural inspection, surveying, rockfall monitoring, and traffic monitoring (Mallela et al., 2017). Implementing UASs for these applications creates new interactions, and therefore new safety concerns, between UAS vehicles, UAS operators, and motor vehicle drivers. Drivers being distracted by UAS operations near roadways is a potential safety concern, particularly as distracted driving is a substantial challenge policy makers and engineers are actively seeking to address (NHTSA, 2018).

This study explored the emerging safety concern of driver distraction and roadside UAS operations using a high-fidelity driving simulator. The aim of this work was to provide quantitative data to recommend policy specifications that are achievable within the current landscape of UAS regulation while also improving the safety of interactions between motor vehicle drivers and roadside UAS operations.

2. Literature review

As UASs are an emerging technology, little prior research has been conducted regarding potential safety concerns. This includes concerns about the interactions of UASs and roadway infrastructure. Therefore, it is vital to understand the current UAS policy landscape around the world. This review explored current UAS policy at various scopes of jurisdiction, culminating in a synthesis of the processes necessary to implement UAS policy in the United States. This literature review concluded with a summary of the current gaps in the literature related to UASs and traffic safety and posed research questions to be answered by this study.

2.1. UAS policy landscape

UAS policy in the around the world is still in its infancy, but the last few years have seen significant strides in policy development and implementation at all governmental levels. As UAS technology evolves and applications continue to develop, the policy landscape surrounding UAS operations continues to be fluid. The following sections explore the existing policies around the world with a more detailed examination of the policy at the federal, state, and local level in the United States.

2.1.1. International UAS policy

Policy regulating UASs is being developed worldwide. The policies are wide ranging and are constantly being augmented and revised. Therese Jones (2017) published an extensive literature review of the regulations of commercial UAS operations in every country in the world. The following list, which was compiled by Jones and quoted here, found that countries could be sorted into the following six categories (ranked from least to most permissive) based on the stringency of their commercial UAS regulations (Jones, 2017):

1. Outright ban – “Countries do not allow drones at all for commercial use.”
2. Effective ban – “Countries have a formal process for commercial drone licensing, but requirements are either impossible to meet or licenses do not appear to have been approved.”
3. Visual line of sight (VLOS) required – “Drones must be operated within VLOS of the pilot, thus limiting their potential range.”
4. Experimental beyond visual line of sight (BVLOS) – “Exceptions to the constant VLOS requirement are possible with certain restrictions and pilot ratings.”
5. Permissive – “Countries have enacted relatively unrestricted legislation on commercial drone use. These countries have a body or regulation that may give operational guidelines or require licensing, registration, and insurance, but upon following proper procedures it is straightforward to operate a commercial delivery drone.”
6. Little to no regulations (“wait-and-see” approach) – “…enacted very little drone regulation and intend to monitor the efficacy of other nations’ regulations.”

The primary concern of policy makers based on the categories in this list is whether UASs can operate BVLOS of the operator. The level of risk likely increases when BVLOS is permitted, and international UAS policy will almost certainly continue to focus on this discussion.

2.1.2. Federal UAS policy in the United States

Congress has given authority of the National Air Space (NAS) to the FAA, designating this agency as the primary regulatory authority over all UAS operations. The FAA Modernization and Reform Act of 2012 (FMRA) and Part 107 of the FAA Regulations are the current laws regulating commercial and recreational UAS operations. This rule, established in 2016, requires FAA designated pilot certification and UAS vehicle registration. In addition, commercial operations must comply with the following operating rules, subject to waivers (Small Unmanned Aircraft Systems, 2016):

- Fly the UAS vehicle within 122 m (400 ft) above the ground level or within 122 m (400 ft) of a structure

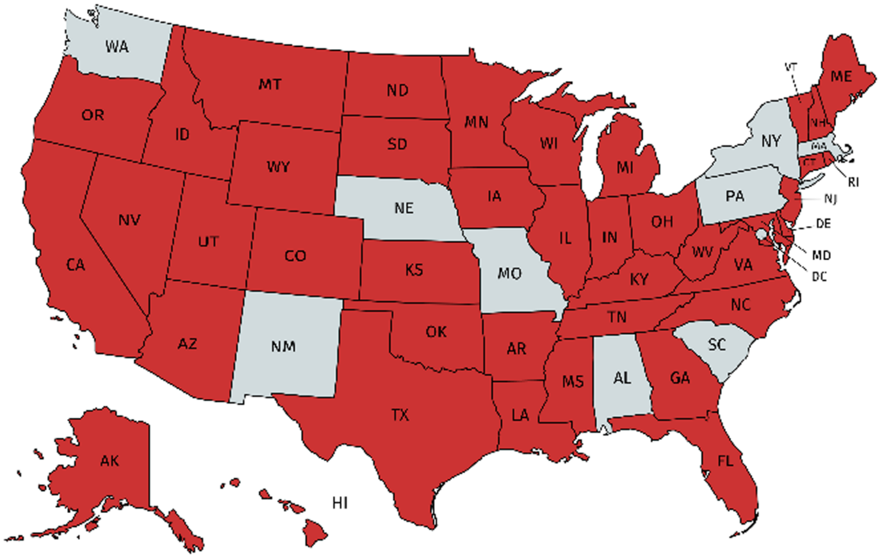

Fig. 1. Map of the 41 states that have enacted UAS legislation (*Courtesy: mapchart.net*).

- Operate the vehicle within line-of-sight
- Do not fly more than 100 mph
- Only operate UAS during the day
- Do not fly over people or moving vehicles
- Do not operate from moving vehicles
- Respect airspace restrictions near airports

The only requirement for recreational UASs under Part 107 is the registration of the vehicle with the FAA. Recreational UAS operations are regulated under Section 336 of the FMRA. These rules are less stringent than the Part 107 requirements for commercial UASs. They stipulate that the pilot (who does not need a certification) must operate the vehicle within visual line-of-sight, follow community-based safety guidelines, and notify air traffic control when planning to operate the UAS within 5 miles of an airport (FAA Modernization and Reform Act, 2012).

2.1.3. State UAS policy in the United States

In addition to federal law and regulation, most states have sought to adopt additional policies to regulate UAS operations. Between 2013 and 2017, 41 states enacted legislation related to UAS operations (Essex, 2016). Fig. 1 shows the states that have enacted state specific UAS policy.

The regulations adopted by these states cover nine broad categories. The National Conference of State Legislatures (NCSL) researches state laws on various topics and publishes summaries of these topics, including the current UAS state law landscape. The NCSL published a 2016 report regarding state UAS laws, with updates in 2016 and 2017 (Essex, 2016). Table 1 describes the nine categories of current UAS laws passed by U.S. states through 2017. These laws and their categorization were compiled by the NCSL

Table 1
Categories of state UAS legislation including number of states enacting per category (Essex, 2016).

Category	No. of States	Description of Category
Preemption	15	Legislation that preempts local governments (county, municipality, etc.) from enacting their own regulations regarding UASs. These regulations range from all-encompassing in some states to including exceptions where localities can have some authority over UAS policy
Privacy	26	Defines search warrant requirements for UAS use by law enforcement and protections from non-governmental privacy violations with UASs
Hobbyists	6	Outlines lawful activities for recreational UAS operations
Commercial Use	6	Outlines lawful uses of UASs for recognized commercial purposes
Government Use	14	Defines allowable uses and processes for use of UASs at state government agencies, particularly in law enforcement agencies
Criminal Penalties	23	Defines penalties for misuse of UASs, such as flying near an airport, interfering with emergency services, weaponizing a UAS, and violating other state UAS laws
Hunting/Fishing	12	Limits use for UASs in hunting and fishing or prohibits UASs from interfering with lawful hunters and fishers
Security Concerns	15	Prohibits UAS use around critical infrastructure, such as power plants and some manufacturing facilities
Studies and Task Forces	15	Directs state agencies and resources to study UAS impacts for regulations and potential applications

and are kept up-to-date on their webpage regarding current UAS state laws (URL: http://www.ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx).

2.1.4. Local UAS policy in the United States

The landscape of UAS policy at the local level is less developed and more fractured. However, the policy question regarding the extent to which local governments can regulate UAS operation is intriguing. Some notable localities have passed UAS specific policy. For example, Miami-Dade County prohibits UAS operations near airports whereas Chicago prohibits UAS flights over community centers, such as schools, hospitals, places of worship, prisons, and police stations (Essex, 2016). A particular local ordinance that drew Federal attention was a policy of the City of Newton, Massachusetts, that outlawed UAS operations within the city limits up to 122 m (400 ft) altitude. In Singer v. Newton (2017) the court determined that this ordinance was in conflict with current federal regulations preventing UAS flights above 122 m (400 ft) altitude, meaning the Newton ordinance completely prevented UAS operation within city limits. As a result of this case, the ordinance in the City of Newton was removed.

2.2. Policy regulating UAS near roadways

Currently, almost no policy exists that regulates UAS operations near public roadways. At the Federal level in the United States, Part 107 notes that a UAS cannot operate above a human being that is not a participant in the operation or "inside a stationary vehicle that can provide reasonable protection from a falling small unmanned aircraft." Therefore, according to this rule, it is unlawful to fly a UAS over non-participants in moving vehicles. As noted, Part 107 does not apply to recreational UASs, so there is no restriction for hobbyists to operate UASs over moving vehicles (including vehicles on public roadways). At the state level in the United States, there are currently no regulations regarding UAS operations near roadways. There are, however, several state laws restricting UAS near critical infrastructure facilities, but these states did not include roads (including bridges and tunnels) in their definitions of critical infrastructure. Because UAS operations are currently not restricted from operating near public roadways, risky interactions may take place.

2.3. UAS as a distraction to drivers

While no formal policy exists, some entities have considered these potentially risky interactions. A report by the Alaska legislature warns UAS users not to operate UASs near busy roadways for fear of causing driver distraction or automobile crashes (Blaisdell and Skaggs, 2015). A survey conducted by the University of Hawaii asked transportation officials from around the country to assess their attitudes regarding the presence of UASs near roadways and traffic safety. Ninety-two percent of respondents identified driver distraction as a potential hazard of UAS operations near roadways, and over half of respondents supported restricting UAS use over interstates, major arterials, and intersections (Kim et al., 2017). This consideration highlights the gap between concern for this topic and policy being implemented to alleviate the potential hazard.

As noted by Kim et al. (2017), a potential safety issue with UASs operating near roadways is the potential for drivers to be visually distracted by the UAS vehicle or operators. A review of the literature supports the connection that a driver taking their eyes off the road can up to double the risk of a crash (Klauer et al., 2006; Simons-Morton et al., 2014). However, no literature exists that measures the potential visual distraction induced by UAS operations near roadways.

2.4. Practice and limitations of the literature

While policy for UAS technology is still emerging, existing policy does create a framework for the practice and implementation of UAS regulation, particularly in the United States. For UAS regulation to continue to be effective and promote safety, it is necessary that this framework be more robust.

There are noted safety and distraction concerns related to interactions between UAS operations and motor vehicle drivers (Blaisdell and Skaggs, 2015; Kim et al., 2017) and little regulatory policy. While the processes for implementing such policy exists in current UAS regulations, there is limited background and research to guide such initiatives. For example, inadequate research exists to document whether drivers are more distracted when UASs are near the roadside. In addition, there is a need for data-driven policy recommendations that could improve safety and leverage existing methods and practices for implementing UAS policy.

2.5. Research questions

To address limitations of the literature related to the safety concerns of drivers being distracted by UASs near roadways, the following research questions were developed:

1. Do drivers look away from the road longer when there is a roadside UAS operation than they do normally when driving?
2. Based on the visual attention of drivers near roadside UAS operations, what policies for roadside UAS operations could improve the safety of drivers and UAS operators?

These questions guided the methods and analysis of this study and seek to produce quantitative data to better understand the effects of UAS operations and their interactions with roadway infrastructure.

3. Methods

The objective of this research study was to explore various characteristics of UAS operations near roadways and evaluate their impact on the visual attention of drivers for recommending UAS policy interventions to improve safety. This study was approved by the Oregon State University (OSU) Institutional Review Board (Study #7547). The primary experimental tool was the OSU driving simulator used in combination with an Applied Science Laboratories (ASL) eye tracking apparatus.

3.1. OSU driving simulator

Driving simulation allows driver behavior and potential safety implications to be measured while minimizing risk to the participant. Many studies evaluating elements of transportation engineering have been performed in driving simulators, since they are safer, more controllable, more repeatable, and more cost effective than field studies (Allen et al., 2011). Validation studies have found that driving simulators do not always demonstrate absolute validity as compared to real-world driving, but they do demonstrate relative validity. Relative validity means that the simulated environment and the real-world driving will not produce the exact same numerical values of driver behavior (e.g., speed, lateral position, risky traffic behaviors) but do produce numerical results of a similar magnitude and direction (Mullen et al., 2011). In addition, several studies have been published that have validated elements of the OSU driving simulator by comparing simulator results to real world or experimental field tests (Moore and Hurwitz, 2013; Neill et al., 2016; Swake et al., 2013). These studies highlight the relative validity of the OSU driving simulator for traffic safety research.

Driving simulation has been used extensively in studies to evaluate driver visual attention and distraction, similar to these studies (Hancock et al., 2003; Horberry et al., 2006; Horrey et al., 2006; Neill et al., 2016; Warner et al., 2017). In addition, driving simulators have been used to evaluate driver distraction from distractors external to the vehicle, such as windmills and billboards (Milloy and Caird, 2009; Stavrinos et al., 2016). Because this project explores the potential of driver distraction towards a UAS operation at the roadside (external to the vehicle), a driving simulator is an appropriate tool to safely observe driver behavior in this scenario. For this experiment, the driving simulator used is located on the OSU campus in Corvallis, Oregon. Additional methodological details for the process of conducting the driving simulator portion of this research can be found in a technical report published by the Oregon Department of Transportation (Hurwitz et al., 2018).

An experiment was designed and conducted in the high-fidelity OSU driving simulator (Fig. 2). The configuration of the simulator is a 2009 Ford Fusion cab mounted on a pitch motion system. The visual environment is created through a project three panel, 180° front display, LCD screens for the side mirrors, and a projected screen behind the car for the rearview mirror. The virtual environment is powered by Realtime Technologies SimCreator software (Version 3.2). In addition, Realtime Technologies SimObserver software (Version 2.02.4) was used in conjunction with cameras in and around the simulator to record a visual of participant behavior during the experiment.

To measure the visual attention of the participant while in the driving simulator, the Mobile Eye-XG eye tracking platform (Fig. 3) from Applied Science Laboratories (ASL) was used.

3.2. Virtual environment

To explore how drivers are distracted by UAS operations near roadways, a common UAS operation configuration was designed and placed in the simulation environment. Per Part 107, UAS operations must have the pilot within line-of-sight of the UAS vehicle at all times, and it is recommended that the pilot be accompanied by a spotter (Small Unmanned Aircraft Systems, 2016). Therefore, an ordinary UAS operation configuration was incorporated in the simulator using a one-meter square quadcopter UAS vehicle placed near a pilot and a spotter avatar (Fig. 4).

Two different roadway environments were used in this experiment. The first, shown in Fig. 5, was a two-lane, rural road with no pedestrian infrastructure surrounded by light agricultural and residential development. The second, shown in Fig. 6, was a light urban roadway with a four-lane, non-divided configuration with pedestrian sidewalks. The road was surrounded by medium to heavy

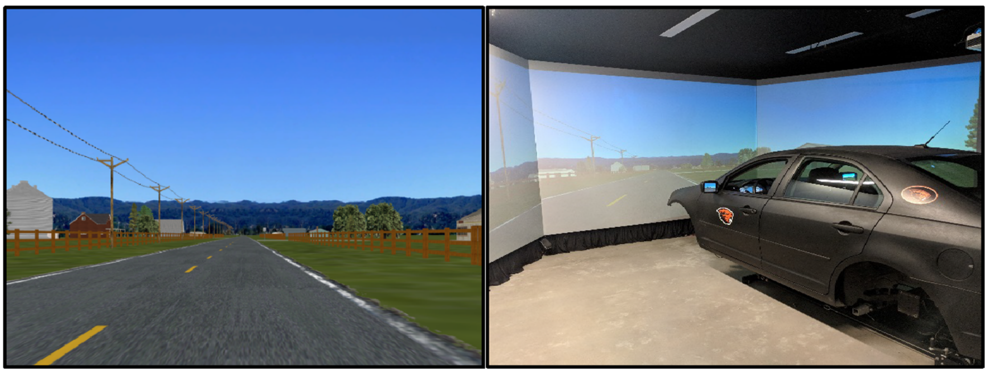

Fig. 2. Simulated environment from the driver's perspective (left) and the OSU driving simulator from outside the vehicle (right).

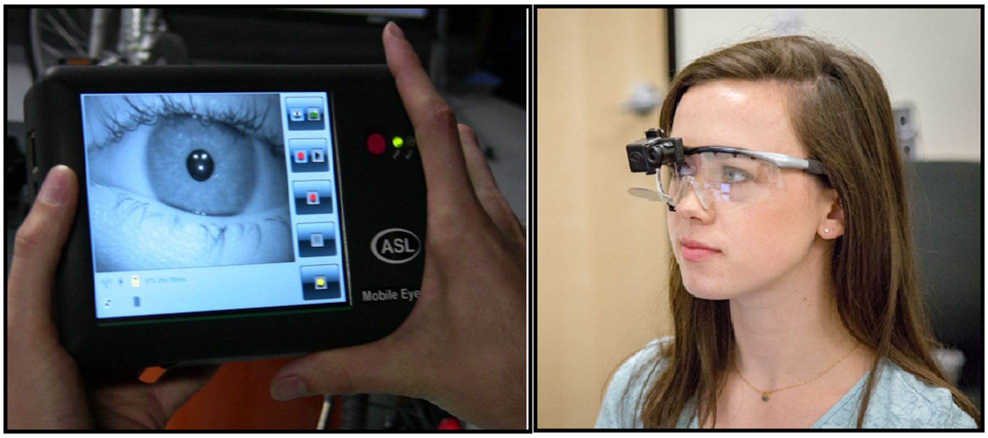

Fig. 3. Demonstration of the Mobile Eye-XG recording unit (left) and the eye tracking glasses (right).

Fig. 4. Typical UAS operation including a quadcopter, pilot, and spotter.

Fig. 5. Two-lane road representing a more rural virtual environment.

Fig. 6. Four-lane road representing a more urban virtual environment.

commercial development. The posted speed limit was 35 mph for both roadways. Both environments had identical weather conditions; participants operated on dry pavement during daylight with a cloudless sky.

3.3. Independent variables

To achieve a broad understanding of the characteristics of UAS operations that may contribute to driver distraction, three independent variables were selected to explore various situations that could be expected of UAS operations. A within-groups, counterbalanced, and partially randomized factorial experimental design was used to explore these three independent variables, as summarized in Table 2.

The three independent variables included in this experiment were the lateral offset of the UAS operation, the flight pattern of the UAS vehicle, and the adjacent land use surrounding the UAS operation. Each combination of these three variables resulted in 18 unique UAS scenarios presented to each experimental participant.

The first variable was the distance of the UAS operation from the right edge line. The inclusion of this variable sought to evaluate the impact of the proximity of the UAS and the operators on driver's visual attention. Three distances [0 m (0 ft), 7.6 m (25 ft), and 15.2 m (50 ft)] were chosen to span the distance from the edge of the travel lane where the UAS operation might be identified by a driver. The first distance, 0 m (0 ft), was chosen to simulate the possibility of UAS operations occurring immediately adjacent to the roadway, such as on a sidewalk. The 15.2 m (50 ft) distance was chosen as the maximum lateral offset to be evaluated in this experiment. Alpha tests during development showed that the UAS operations were often obscured by roadside structures and vegetation at lateral offsets of more than 15.2 m (50 ft), particularly in more urban roadside environments. The 7.6 m (25 ft) distance was chosen as the midpoint between the two extremes to understand any potential trends in visual attention across the range of lateral offsets. More intermediate distances were not evaluated given constraints of driving simulation and a within-groups factorial experimental design.

The second variable was the flight pattern of the UAS vehicle. Most often, UAS vehicles are piloted in (1) slow, predictable scanning patterns; (2) quick, erratic racing patterns; or (3) in an initial takeoff or landing pattern. All three of these patterns were assigned to the UAS vehicle in the simulator, and the UAS followed one of these patterns as the participant passed in the simulated environment.

The final independent variable was the difference between rural and urban land use surrounding the UAS operation. There is potential that the distraction from UAS operations is dependent on the volume of other elements in the participant's visual field.

Table 2
Summary of levels for the three independent variables.

Variable	Level	Description
Lateral Offset	1	UAS operation located 0 m (0 ft) from the right road edge
	2	UAS operation located 7.6 m (25 ft) from the right road edge
	3	UAS operation located 15.2 m (50 ft) from the right road edge
Flight Pattern	1	UAS vehicle performing a takeoff flight pattern
	2	UAS vehicle performing a scanning flight pattern
	3	UAS vehicle performing a racing flight pattern
Land Use	1	UAS operation located in a rural environment
	2	UAS operation located in an urban environment

3.4. Participant demographics

Participants aged 18–75 were recruited from the Corvallis, Oregon, area through paper flyers, email listserves, and social media. Requirements for participation included having a valid driver's license and at least 1 year of driving experience. A total of 54 individuals participated in the study. Thirteen of those participants (24%) experienced simulator sickness and did not complete the experiment. Equipment issues resulted in the loss of eye-tracking data from an additional 11 participants (20%). In total, complete data sets (including eye tracking records) were collected from 30 participants. Sixteen of these participants were male and 14 were female. Participants ranged in age from 18 to 70 years (M_{age} = 29.4, SD_{age} = 12.9). The sample size of 30 was sufficient to perform a statistical analysis, and many previous driving simulator studies have had a participant sample size of 30 or fewer (Donmez et al., 2006; Milloy and Caird, 2009; Owens et al., 2011; Warner et al., 2017).

3.5. Visual attention data processing

Visual attention data were collected from an ASL Mobile Eye-XG system. For each participant, the eye tracking system was calibrated so the recorded video from the eye tracker accurately recorded the participant's eye movements and showed where the participant was looking in their visual field. Human eye movements consist of fixations and saccades. Fixations are the result of the participant's gaze being directed toward a single point for some duration of time. Saccades are eye movements between fixations (Green, 2007). The ASL Mobile Eye-XG system was set to define a fixation as any gaze at a single location of at least 100 ms for this study.

3.5.1. UAS operation events

To understand the visual attention patterns of the participants in response to various UAS operations, the total fixation duration (TFD) of each participant on each of the 18 UAS operations was determined. Data were reduced by isolating each of the UAS scenarios to the portion where the UAS operation was visible to the participant. These portions ranged from approximately 4 to 11 s depending on the speed of the participant and the location of the UAS operation. For each UAS event, two areas of interest (AOIs) were drawn to determine the TFD of each participant's gaze within each AOI. The first AOI was a rectangular box encompassing just the UAS vehicle, the pilot, and the spotter. This AOI measures the participants' TFD on the UAS operation as they drive past. The second AOI was drawn to encompass the entire visual field to the right of the roadside, including the UAS operation and the surrounding environment so that the participants' TFD off the roadway during the UAS event could be measured.

3.5.2. Control

A control segment was included in the experiment to establish a baseline of the participants' off-road visual attention during the experiment without the influence of a UAS operation. For each participant, two control segments were evaluated: one in the rural environment and one in the urban environment. These two control segments were in the same location for every participant. The lengths of the control segments were determined per participant based on their average speed to provide an equal comparison between the control segments and the experimental segments with the UAS operations. A single AOI encompassing the entire visual field to the right side of the road was drawn for the duration of both the rural and urban control segments. The AOIs for the control scenarios were drawn using the same approach as the larger AOIs in the UAS event segments. The TFD on these AOIs was recorded as a control value for the time drivers take their eyes off the road during a typical simulated driving task.

3.6. Data analysis

Two methods were implemented to analyze the data from this study. To compare the visual attention in control and experimental segments with UAS operations, analysis of variance (ANOVA) tests were conducted, and a Dunnett's post hoc method was used. The use of Dunnett's method is appropriate for this analysis as it is specific to the situation where multiple experimental groups are being compared to a single control group (Ramsey and Schafer, 2002).

The second statistical method implemented was a Linear Mixed Model (LMM). A LMM model was chosen for analysis because (1) of its ability to handle the errors generated from repeated subject variables as the participants are exposed to all scenarios, (2) it can handle fixed or random effects, (3) categorical and continuous variables can easily be accommodated, and (4) the probability of Type I error occurring is low (Jashami et al., 2019.). A potential limitation of LMM is that more distributional assumptions need to be addressed (Maruyama, 2008). The sample size for this study was 30 participants, which is greater than the minimum of 20 required for a LMM analysis (Huber et al., 2015). Therefore, the LMM was chosen to model the data and is formulated as follows:

$$y_{ij} = \beta_0 + \beta_1 X_{ij} + b_{i0} + b_{i1} X_{ij} + \varepsilon_{ij},$$

$$b_{i0} \ \text{iidN}(0, \sigma_0^2),$$

$$b_{i1} \ \text{iidN}(0, \sigma_1^2),$$

$$\varepsilon_{ij} \ \text{iidN}(0, \sigma_\varepsilon^2).$$

where β_0 is the intercept at the population level, and β_1 is the slope (both are for the fixed effect). b_{i0} is the random intercept of the i^{th}

participant and b_{i1} is the random slope for the same participant which follow a mean normal distribution with variances σ_{b0}^2 and σ_{b1}^2 respectively. ε_{ij} is the error term. Hence, (b_{i0}, b_{i1}) and ε_{ij} are assumed to be independent. The model was developed using the statistical software Minitab for Windows (version 18.1) to consider the independent variables of lateral offset, flight pattern, and land use. These variables were included in the model as fixed effects, as well as the participant demographic characteristics of age, gender, level of education, race, income, vehicle type, and miles driven. Random effects for the participant variable were also included in the model.

A LMM was used to estimate the relationship between UAS operations and participant's mean TFD, which is appropriate given the repeated measures nature of the experimental design, where each participant experienced each scenario (Cnaan et al., 1997). It was necessary that both fixed and random effects be included in the model. Pearson's correlation coefficient was used to identify any correlated variables. In the case of statistically significant effects, custom post hoc contrasts were performed for multiple comparisons using Fisher's Least Significant Difference (LSD). All statistical analyses were performed at a 95% confidence level. Restricted Maximum Likelihood estimates were used in development of this model.

4. Results

To understand the effect of roadside UAS operations on drivers, the visual attention results from the eye tracker during the simulation were explored. The visual attention of participants was evaluated based on the participant's TFD on the UAS operation and the area off the road surrounding the operation. The analysis was divided into two parts: the first sought to determine if any of the UAS events the participants experienced resulted in a higher TFD off the roadway than normal driving, and the second explored the various characteristics of UAS operations and determined which resulted in an effect on the participant's TFD on the UAS operation.

4.1. Experimental control analysis

For each of the land use variables (rural and urban) a control segment was recorded to determine a baseline TFD for the participants in each of the environments. The experimental design resulted in 9 UAS events located in the rural environment and 9 located in the urban environment. It was hypothesized that the visual attention patterns are different in the two environments due to different concentrations of visual clutter, so the comparison to baseline driving behavior was divided between the rural and urban environment scenarios.

The left side of Fig. 7 shows a boxplot of the TFD of the nine experimental scenarios and the control in the rural environment. The right side of Fig. 7 shows a boxplot of the TFD of the nine experimental scenarios and the control in the urban environment. A visual inspection of these boxplots shows that the TFD for the experimental scenarios is generally higher than the control, particularly in the rural environment. There is less variability in the TFD in the rural experimental scenarios than in the urban experimental scenarios. However, there does appear to be a trend in both environments that as the lateral offset increases, the TFD decreases.

First, ANOVA tests were performed to determine if there are differences between any of the mean TFDs in the rural and urban scenarios. For both analyses, the TFDs for the nine experimental scenarios and the control scenario were included. The analysis of

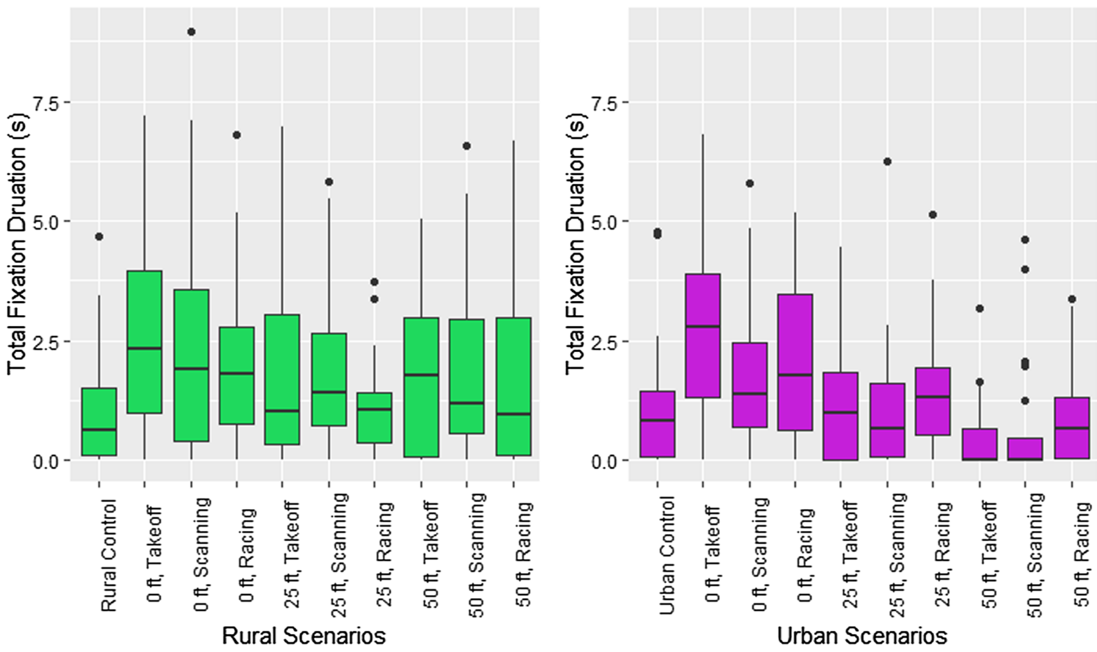

Fig. 7. Boxplot of TFD for the rural scenarios (left) and the urban scenarios (right).

Table 3
Summary of Dunnett's post hoc method for the rural environment.

Rural Comparison	Estimate	Std. Error	t	*P*
0 m, Takeoff - Control	1.788	0.444	4.03	< **0.001***
0 m, Scanning - Control	1.300	0.463	2.80	**0.044***
0 m, Racing - Control	1.054	0.365	2.89	**0.034***
7.6 m, Takeoff - Control	0.881	0.417	2.11	0.245
7.6 m, Scanning - Control	0.862	0.352	2.45	0.114
7.6 m, Racing - Control	0.150	0.256	0.54	0.999
15.2 m, Takeoff - Control	0.811	0.357	2.27	0.172
15.2 m, Scanning - Control	1.039	0.404	2.57	0.083
15.2 m, Racing - Control	0.739	0.403	1.84	0.412

* Significant at the 95% confidence level.

variance showed that the effect of UAS scenarios on TFD was significant at the 95% confidence level in both rural and urban environments (Rural: [$F(9, 290) = 2.65$, $P = 0.0057$], Urban: [$F(9, 290) = 8.45$, $P = < 0.0001$]).

Given the statistically significant results in the ANOVA, a Dunnett's post hoc method was implemented to determine if any of the experimental scenarios with a UAS event had a significantly higher mean TFD than the control representing normal, baseline driving. Tables 3 and 4 provide the results of Dunnett's method for the comparison of the mean TFD to the control scenario for the rural and urban environments, respectively.

Results from Table 3 show that the TFDs at the 0 m (0 ft) offsets in the rural environment were all statistically higher than the control TFD. This was true for all three flight patterns. Table 4 shows that in the urban environment only the TFD for the 0 m (0ft) condition with the takeoff flight pattern resulted in a statistically higher TFD than the control TFD. These results show that in both rural and urban environments, UAS operations immediately adjacent to the roadside can result in a statistically significant amount of increased glancing away from the roadway.

4.2. Visual attention model

After determining that some instances of UAS operations can result in more visual attention being allocated to the roadside than during typical driving, it was necessary to understand the relationship of the characteristics of UAS operations with the TFD of the participants.

4.2.1. Descriptive statistics

For each UAS operation, the total duration of time that the participants' eyes are fixated on the UAS operation is the TFD. Table 5 summarizes the mean and standard deviation (SD) values for the TFD of all 30 participants for each of the combinations of the three independent variables and their levels.

4.2.2. Linear Mixed model

A LMM was used to estimate the relationship between UAS operation characteristics and mean TFD of the participants. The results of the model are shown in Table 6. The random effect was significant (Wald Z = 3.50, $p < 0.001$), which suggests that it was necessary to treat the participant as a random factor in the model. The intraclass correlation coefficient (ICC) of the random factor was calculated as 0.513 with a 95% confidence interval [0.44, 0.63]. This value indicates variance accounted for by the per-subject clustering in the data, otherwise described as the proportion of between-subject variance to the total between-subject and within-subject variance (O'Dwyer and Parker, 2014). Since the ICC value was higher than the cutoff of 0.1, conducting multi-level model was an appropriate analysis for this clustered set of data (Vajargah and Nikbakht, 2015).

All three independent variable characteristics of UAS operations were found to have a significant impact on the TFD of the

Table 4
Summary of Dunnett's post hoc method for the urban environment.

Urban Comparison	Estimate	Std. Error	t	*P*
0 m, Takeoff - Control	1.667	0.414	4.03	< **0.001***
0 m, Scanning - Control	0.548	0.358	1.53	0.551
0 m, Racing - Control	0.915	0.379	2.41	0.104
7.6 m, Takeoff - Control	0.111	0.323	0.35	0.999
7.6 m, Scanning – Control	−0.040	0.341	−0.12	1.000
7.6 m, Racing - Control	0.309	0.326	0.95	0.929
15.2 m, Takeoff - Control	−0.680	0.270	−2.51	0.081
15.2 m, Scanning - Control	−0.524	0.321	−1.63	0.475
15.2 m, Racing - Control	−0.239	0.291	−0.82	0.968

* Significant at the 95% confidence level.

Table 5
Descriptive statistics of TFD (in seconds).

Lateral Offset	Stats	Rural Land Use			Urban Land Use		
		Takeoff	Scanning	Racing	Takeoff	Scanning	Racing
0 m Offset	Mean	2.15	1.56	1.38	2.33	0.96	1.60
	SD	2.08	1.73	1.24	1.66	0.98	1.33
	Max	5.65	7.11	5.04	5.04	3.27	4.11
	Min	0	0	0	0	0	0
7.6 m Offset	Mean	0.98	1.20	0.70	0.66	0.49	0.72
	SD	0.89	1.14	0.79	0.91	0.68	0.87
	Max	2.67	5.36	2.8	3.07	2.32	4.14
	Min	0	0	0	0	0	0
15.2 m Offset	Mean	1.06	1.20	0.66	0.08	0.62	0.50
	SD	1.09	1.21	0.96	0.19	0.96	0.68
	Max	3.43	3.59	3.47	0.80	3.29	2.39
	Min	0	0	0	0	0	0

Table 6
Summary of Estimated Models for TFD.

Variable	Levels	Estimate	DF	*P*
Participant random effect (SD)	–	(0.74)	–	< **0.001***
Constant	–	1.03	29	< **0.001***
Lateral Offset	15.6 m offset	−0.95	493	< **0.001***
	7.6 m offset	−0.83	493	< **0.001***
	0 m offset	Base	–	–
Flight Pattern	Racing	−0.29	493	**0.002***
	Scanning	−0.24	493	**0.050***
	Takeoff	Base	–	–
Land Use	Urban	−0.31	493	< **0.001***
	Rural	Base	–	–

Summary Statistics			
Adjusted R^2	50.11%	Observations	540
−2Log Likelihood	1578.13	Participants	30
AIC	1649.25	Observations/Participant	18

* Significant at the 95% confidence level.

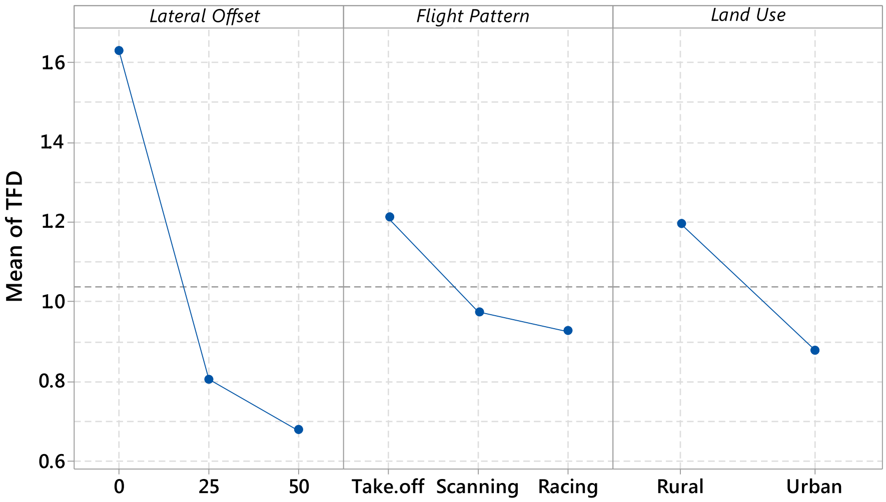

Fig. 8. Primary effects plot of UAS operations factors on mean TFD.

participants (Fig. 8). Regardless of the flight pattern and land use, a participant had a TFD of almost one second longer when the lateral offset was 0 m (0 ft) than when the offset was 7.6 m (25 ft) or 15.2 m (50 ft) ($p < 0.001$). When the UAS operation had a scanning or racing flight pattern, the participants spent, on average, about 0.25 s of fixation less than on the takeoff flight pattern ($p = 0.050$ and 0.002, respectively). Finally, the land use variable found that the average TFD was 0.3 s higher in the rural

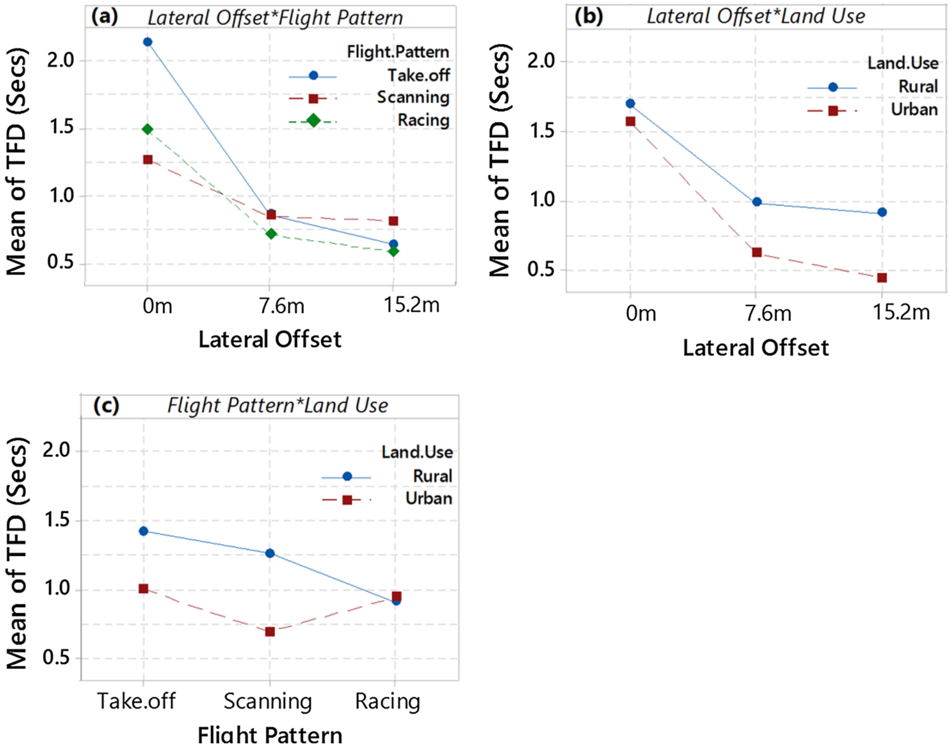

Fig. 9. Two-way interactions of UAS operations variables on mean Total Fixation Durations (TFD): (a) two-way interactions plot between lateral offset and flight pattern, (b) two-way interactions plot between lateral offset and land use, and (c) two-way interactions plot between flight pattern and land use.

environment than in the urban environment ($p < 0.001$). None of the demographic characteristics were found to be statistically significant. Fig. 8 plots the mean TFD for each level of lateral offset, flight pattern, and land use.

Moreover, LMM revealed two statistically meaningful two-way interactions between lateral offset and flight pattern ($p < 0.001$), and between flight pattern and land use ($p < 0.001$) as shown in Fig. 9a and c, respectively. However, the interaction term between lateral offset and land use was not significant (Fig. 9b). In Fig. 9, the y-axis shows mean TFD. The x-axis in plots Fig. 9a and b shows the three levels of lateral offset treatment, and the x-axis in Fig. 9c shows the three levels of flight pattern treatment. For example, Fig. 9a plots the interaction between the levels of lateral offset and the levels of flight pattern. Regardless of land use, on average, participants spent more time looking at the takeoff pattern when the lateral offset was 0 m (0 ft) compared to 7.6 m (25 ft) and 15.2 m (50 ft). Meanwhile, while holding the lateral offset constant, participants spent more time fixating on the takeoff pattern in the rural area as compared with the urban area. Additionally, the three-way interaction between the UAS operations variables was not significant ($p > 0.05$). All treatment factors were inspected by pairwise comparison.

5. Discussion

This study used a high-fidelity driving simulator experiment to produce visual attention data from drivers as they drove past roadside UAS operations. This data was analyzed using a control analysis and a LMM to determine patterns in driver's visual attention that could be used to evaluate the research questions for this study. The following discussion highlights the findings from this study and places them back in the context of the literature related to UAS policy and traffic safety.

5.1. UAS as a distraction

The first research question, "Do drivers look away from the road longer when there is a roadside UAS operation than they do normally when driving?", evaluated if UAS operations were a meaningful element of the visual field such that drivers would look away from the road for longer than they would during normal driving. Across both a control analysis and an LMM statistical analysis, UAS operations near roadways do result in higher TFDs off the roadway toward the UAS operation depending on the specific characteristics of the UAS operation such as lateral offset, flight pattern, and land use.

The control analysis found that, in both rural and urban scenarios, there were instances of UAS operations immediately adjacent to the edge line (0 m offset) that resulted in a TFD off the roadway higher than baseline driving. None of the mean TFDs of the UAS operations at 7.6 m (25 ft) and 15.2 m (50 ft) were statistically different than the mean TFDs of the baseline driving. This indicates that UAS operations within 7.6 m (25 ft) of the edge line still resulted in distraction by drivers. The results of the LMM further confirm that driver distraction was more pronounced at the 0 m (0 ft) offset UAS than the other lateral offsets.

The significant interactions in the LMM also noted that the takeoff flight pattern drew more visual attention, particularly when the operations were adjacent to the edge line (0 m offset) and when the operation was conducted in the rural environment. Since all UAS must have a takeoff and landing sequence, all UAS operations will incorporate this most distracting flight pattern. The distraction to drivers of the UAS takeoff and landing procedures is further increased by the frequency of these procedures. Most UAS on the market today only have a short battery life of between 10 and 50 min (Harrington, 2015), meaning that operators will have to land and takeoff the UAS vehicle frequently to charge or switch the battery when performing UAS operations.

Another result consistent across the control analysis and the LMM was that UAS operations pose more of a distraction to drivers when the operation is in a rural environment. Based on these results, it is assumed that UAS operations are more conspicuous to drivers in the rural environment because there is less visual clutter than the urban environment. This variation based on the environment poses a unique challenge for policy makers as the definition of "rural" is more subjective.

5.2. Policy recommendations

The second research question, "Based on the visual attention of drivers near roadside UAS operations, what policies for roadside UAS operations could improve the safety of drivers and UAS operators?", was evaluated using the results from the control analysis and the LMM, as well as the conclusions from the first research question in this study.

As noted, previous research has shown that drivers taking their eyes off the road is a risky behavior that decreases safety, and this experiment has demonstrated that there are instances where UAS operations can result in this type of unsafe driver behavior. Policy changes can be implemented to mitigate safety concerns and minimize the frequency of risky interactions between UAS operations and drivers on public roadways. The findings from the driving simulator experiment point to the following guidelines for policy to improve driver and UAS operator safety:

- Prohibit UAS vehicles and operators, regardless of whether a hobbyist or a commercial entity, from operating a UAS within 7.6 m (25 ft) of the edge line (or lane edge when no edge line is present).
- Ensure that takeoff and landing maneuvers for UAS vehicles are not conducted within 7.6 m (25 ft) of the road edge and consider requiring these maneuvers to be restricted to even further from the edge line.
- Consider more stringent prohibitions in jurisdictions where the roadside characteristics could be defined as rural. These prohibitions based on "rurality" might be most effectively divided at the county level, where the Office of Management of Budget (OMB) defines rural at the county level designations of metropolitan, micropolitan, or neither, based on the size of population centers within these counties (Coburn et al., 2007).
- Exemptions to these limitations should be considered for activities that develop an appropriate safety plan and seek a waiver from the jurisdictional government agency. Emergency response activities should also be considered for exemption from these restrictions.

The listed policy recommendations represent a minimum standard based on the results of the presented experiment. Safety could be further improved if more stringent versions of these policies were to be implemented, provided the restrictions to not severely impede UAS use for different applications.

5.3. Policy implementation

The exploration of the UAS policy landscape conducted in the literature review of this work highlighted that there is a framework in place for properly implementing new UAS policies at various levels of government in the United States. However, while this framework exists, the multi-tiered managerial system for UAS operations has resulted in a confounding process for implementing UAS related policies.

Therefore, to accompany the policy recommendations outlined in this paper, Fig. 10 provides a tool to assist policymakers in navigating the current regulatory structure of UAS policy. The figure contains a flowchart outlining the process of passing a hypothetical regulation in which a municipality is seeking to limit UAS operations near roadway infrastructure. The left side of the figure lists the steps that need to be taken to implement a UAS related policy, and the right side of the figure presents a detailed example of the manifestation of those steps as they would relate to a UAS related policy being implemented at a municipal level. The municipal level was chosen for this policy example since UAS policy implementation is more restrictive below the state level.

Depending on the individual government organization, additional steps from what is listed in Fig. 10 could be required. In addition, as federal and state regulation continue to evolve, some of these steps may change. However, this process is a comprehensive and reliable approach to achieve effective UAS regulation implementation.

6. Conclusions

UASs are still an emerging and developing technology; as a result, there are areas related to UAS safety that research and policy have yet to address. One such example highlighted in the literature was the potential concern for drivers to be distracted by UASs operating near roadways. Existing policy did not address this safety concern, and no research showed whether UASs near roadways

1. Define the challenge	**Problem:** A municipality is concerned about a local UAS racing league practicing too near to a local highway as a safety issue for the drivers and the UAS operators. **Desired Solution:** Pass a city ordinance that prevents UAS operations near public roadways.
2. Explore preemptions	**Federal Preemptions:** UAS operations occur within the National Air Space (NAS) in the United States, and fall under the authority of the FAA. However, the FAA has declined to preempt all state and local laws regarding UAS operations, which allows the municipality to propose UAS ordinances provided they do not contradict existing federal law (CITE). **State Preemptions:** Fifteen states have passed laws preempting localities from passing ordinances related to UAS operations (CITE). In this example, the municipality is not in one of the current 15 states, meaning the municipality can pass ordinances related to UAS operations provided they do not contradict existing state law.
3. Explore regulations	**Federal Regulations:** Federal regulations do not specifically reference UAS operations near public roadways. However, FAA policy states that UAS operations cannot fly directly over non-participants including non-participants in moving vehicles (CITE). In addition, this policy only applies to hobby UAS operations, meaning that for hobby UAS users, there is no prohibition of operating a UAS near/over a roadway facility. Therefore, a municipal ordinance related to UAS operations and public roadways would not be in conflict with existing Federal law. **State Regulations:** Currently, no states have a regulation regarding UAS use around roadway facilities. XX states have adopted legislation preventing UAS operations near critical infrastructure. None of the existing statutes define critical infrastructure to include roadway infrastructure, including bridges and tunnels, though some include rail yards and shipping ports (CITE). This municipality has the authority within its state to pass an ordinance related to UAS operation and roadway infrastructure.
4. Explore recommendations	**Federal Recommendations:** The FAA recommends that municipalities consult with the FAA regarding potential ordinances that will prohibit anyone from operating a UAS "within certain distances of landmark" (CITE). For this example, the city is seeking to prevent UAs operations within a certain distance of public roadways, and should consult with the FAA.
5. Determine specifics of policy	**Scope:** The municipality must define the scope of the proposed regulation, including the types of UAS operations that will be encompassed. This municipality is currently concerned about the racing league (hobby UAS), but are aware that commercial operations may soon be operating near roadways, so they choose to write the ordinance to include a prohibition of hobby and commercial UAS users near roadways. **Imposed Limitations:** The municipality should consult all existing research (such as this study) to determine how to make the UAS limitation achieve a high safety benefit while being minimally obtrusive to UAS operators. In this case, the municipality consulted this study and chose to write the ordinance to prevent UAS operations within 25 ft. of any public roadway. **Penalties:** The municipality must define the penalties for violating the boundary, which could include criminal penalties (e.g. a misdemeanor) or financial penalties.
6. Implement and enforce	**Implementation:** Once all preemptions, regulations, and recommendations have been met, and the municipality has determined the specifics of the desired regulation, the municipality can implement a city ordinance that prevents all hoppy and commercial UAS operations within 25 ft. of public roadways. **Enforcement:** After the ordinance is passed, the municipality should take steps to inform the public of the new policy and be active in enforcing the ordinance through the local law enforcement. This will encourage greater compliance and maximize the safety benefit of the ordinance.
7. Monitor future policy	Policies and regulations relating to UAS operations continue to emerge at the Federal and state level. Even after this municipality has enacted as UAS policy, it must continually monitor other regulatory action that may preempt or contradict the standing policy and make adjustments accordingly.

Fig. 10. Steps for implementing UAS legislation at the local level.

actually caused drivers to look away from the roadway for longer than they do under normal driving conditions.

Through the use of a high-fidelity driving simulator, this study demonstrated that UAS operations near roadways do attract drivers' attention, particularly when the UAS operations are within 7.6 m (25 ft) of the road edge and in a rural environment. Based on these findings, policy recommendations, including limiting UAS operations within 7.6 m (25 ft) of the road edge and considering more stringent regulations in rural environments, can be implemented in the current framework of UAS policy in the United States. These data-driven policy recommendations contribute an increased understanding of the way UASs interact with motor vehicle drivers, as well as provide a justification for the implementation of policy regulating UAS operations near roadways.

While the results of this study do provide insight into UAS interactions with drivers near roadways, there were also limitations to this study. Given resource constraints and the intrinsic limitations of driving simulator studies (i.e. driver fatigue), a limited number of variables could be evaluated. For example, only three lateral offset distances (0 m, 7.6 m, and 15.2 m) were evaluated. With more resources, more lateral offset distances could have been studied, providing a greater understanding of the effect of lateral offset on the visual attention of drivers. The same is true for the other independent variables of flight pattern and land use.

Future research could explore some of these limitations and add detail to the existing findings. In addition, future work could identify measures that alert drivers that UAS operations are near the roadway for official activities, such as signs used for survey work, bridge inspections, construction, and maintenance activities. Policy at any level of government is still in its infancy related to UASs, but as policy continues to be implemented, studies are necessary to evaluate the impact and effectiveness of these policies to further improve future policy.

The present and future benefit of UAS operations to many industries is undeniable. This future is even brighter if UASs can be integrated with effective restrictions that promote the safety of UAS operators and drivers.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trc.2019.09.012.

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