# INVESTIGATING THE THREATS OF UNMANNED AIRCRAFT SYSTEMS (UAS) AT AIRPORTS

by

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Special thanks to my family for their endless support.

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# GLOSSARY

Drone – an aircraft without a pilot that is controlled by someone on the ground (Cambridge Dictionary, n.d. -a).

Sighting – an occasion when you see something or someone, especially when they are rare or trying to hide (Cambridge Dictionary, n.d. -b).

Small unmanned aircraft – an unmanned aircraft weighing less than 55 pounds on takeoff, including everything that is on board or otherwise attached to the aircraft (Small Unmanned Aircraft Systems, 2016).

Small unmanned aircraft system (sUAS) – a small unmanned aircraft and its associated elements, including communication links and the components that control the small unmanned aircraft, required for the safe and efficient operation of the small unmanned aircraft in the national airspace system (Small Unmanned Aircraft Systems, 2016).

Unmanned aircraft – an aircraft operated without the possibility of direct human intervention from within or on the aircraft (Small Unmanned Aircraft Systems, 2016).

# LIST OF ABBREVIATIONS

ADVZY - Advisory

AEP - Airport Emergency Plan

ARTCC - Air Route Traffic Control Center

ASPM - Aviation System Performance Metrics

ATC - Air Traffic Control

ATCSCC - Air Traffic Control System Command Center

AWS - Alert Warning System

BTS - Bureau of Transportation Statistics

CAA - Civil Aviation Authority

CFR - Code of Federal Regulation

DXB - Dubai International Airport

EVV - Evansville Regional Airport

EWR - Newark Liberty International Airport

FAA - Federal Aviation Administration

FMRA - FAA Modernization and Reform Act

FSDO - Flight Standards District Offices

GA - General Aviation

HNB - Huntingburg Regional Airport

IFR - Instrument Flight Rule

IND - Indianapolis International Airport

IRB - Institutional Review Board

JFK - John F. Kennedy International Airport

LAF - Purdue University Airport

LEO - Law Enforcement Officer

LGA - LaGuardia Airport

LGB - Long Beach Airport

MOR - Mandatory Occurrence Report

NAS - National Airspace System

NPIAS - National Plan of Integrated Airport Systems

NTSB - National Transportation Safety Board

OIS - Operational Information System

OPSNET - Operations Network

ORD - Chicago O’Hare International Airport

PAPI - Precision Approach Path Indicator

POE - Probability of Extension

sUAS - Small Unmanned Aircraft Systems

TEB - Teterboro Airport

TRACON - Terminal Radar Approach Control

TSA - Transportation Security Administration

UAS - Unmanned Aircraft Systems

UAST - Unmanned Aircraft Safety Team

U.S.C. - United States Code

UTC - Coordinated Universal Time

VFR - Visual Flight Rule

VLOS - Visual Line of Sight

# ABSTRACT

Safety is the top priority for the aviation industry and a safe airport environment is essential to aviation safety. However, due to the increasing prevalence of UAS in recent years, UAS sightings have become a potential threat to airports. When UAS appear in the vicinity of airports, they bring safety concerns and result in negative operational and economic impacts on airports. Since the FAA's mission is to provide the safest and most efficient aerospace system in the world, further research regarding the threat of UAS sightings to airports is needed. The purpose of this study is to investigate the threat of UAS to airports and in the national airspace system (NAS). This study includes three primary components: the analysis of 6,551 Federal Aviation Administration (FAA) UAS sighting reports, a case study of the impacts of the UAS sighting at Newark Liberty International Airport (EWR) on January 22, 2019, and a synthesis of airport operator perspectives based on interviews with airport personnel at five airports. The analysis of UAS sighting reports shows the characteristics of UAS sightings, the case study on EWR UAS illustrates the impact of the UAS sighting at the airport, and interview results illustrate the current perspective of airport operators regarding the risk of UAS. Along with the results, the scientific methods of identifying and analyzing the characteristics of UAS sightings in controlled airspace close to airports could be used by researchers to study UAS sightings in the future. Findings from this study may be beneficial to multiple stakeholders, including airport personnel, regulators, entrepreneurs, and vendors in the aviation industry.

# CHAPTER 1. INTRODUCTION

Chapter 1 provides an introduction to the study, the purpose of the study, the research questions and the significance of the research. Next, the scope of the study is presented, followed by the assumptions, limitations, and delimitations.

## 1.1 Statement of Purpose

Any midair collision between an aircraft and an object is dangerous to the aircraft, as exemplified by the accident of US Airways Flight 1549 in January 2009. The flight was struck by a flock of Canada geese and consequently lost all engine power (National Transportation Safety Board [NTSB], 2010). The weight of a Canada goose, usually between 5.3 to 14.3 pounds, is exceeded by some professional-quality camera UAS (Irving, 2017; Mowbray et al., 2020) and research indicates that UAS can cause more damage in a collision with an airliner than a similarly-sized bird with an equivalent initial mass and velocity (Civil Aviation Authority [CAA], 2018a; Federal Aviation Administration [FAA], 2017a).

Because UAS have the potential to cause an aircraft incident or accident, the incursion of a UAS into the airspace surrounding the airport can cause an airport delay or even a shutdown, which may disrupt airport operations and can lead to significant economic losses. These impacts have been demonstrated by unmanned aircraft systems (UAS) sightings at major airports around the world. The UAS sightings at Gatwick Airport, the second largest airport in the U.K., disrupted about 140,000 passengers and 1,000 flights during the 36-hour shutdown in December 2018 ("Gatwick Drone Chaos", 2019; Morisset & Odoni, 2011). Airports in Newark, New Jersey; Auckland, New Zealand; and Dubai, the U.A.E. have also had to shut down because of UAS sightings ("Drone at Auckland airport", 2018; Pennington, 2016; Shepardson, 2019).

The UAS sightings are a fairly new threat to aviation. Compared to other risks to aircraft and airports, there has not historically been sufficient data to develop reliable statistics about the safety of UAS (Fortes et al., 2016; Ozuncer et al., 2011). Moreover, the prevalence of UAS has grown dramatically in recent years due to advances in UAS technology, reduced UAS costs, and the promulgation of 14 Code of Federal Regulation (CFR) Part 107, which provides a regulatory framework for the operation of small UAS (sUAS) in the U.S.

Given the potential risk of UAS sightings, the increasing number of UAS, and the lack of accepted and thorough research, it was appropriate to investigate the characteristics of UAS sightings and the operational impacts of unauthorized UAS incursions into controlled airspace at airports in the U.S. The purpose of this study was to investigate the threat of UAS to airports and in the national airspace system (NAS). This study was consistent with the FAA's (2019a) mission of providing the safest and most efficient aerospace system in the world.

## 1.2 Research Questions

The research questions were as follows:

1. What are the characteristics of UAS sightings including temporal distribution, proximity, altitude, distance from the airport, type of manned aircraft operation, severity, and airport category of nearby or referenced airport?
2. What are the operational impacts on airports due to a UAS sighting?
3. What are the current perspectives of airport regarding UAS?

## 1.3 Significance

Safety is the top priority for the aviation industry and a safe airport environment is essential to aviation safety. However, due to the increasing prevalence of UAS in recent years, UAS sightings have become a potential threat to airports. When UAS appear in the vicinity of airports, they bring safety concerns and result in negative operational and economic impacts on airports. This study provides an in-depth analysis of the threat of UAS sightings to airports.

The scientific methods of identifying and analyzing the characteristics of UAS sightings in controlled airspace close to airports could be used by researchers to study UAS sightings in the future. Findings from this study may be beneficial to multiple stakeholders. Airport management could establish effective proactive and reactive countermeasures to reduce and prevent UAS sightings by becoming aware of the characteristics of UAS sightings. Airport operations could gain a better understanding of the impacts of UAS sightings on airport operations and learn about how to handle a UAS sighting at their airport. Policymakers, regulators, entrepreneurs, or vendors who are looking for solutions to improve UAS safety at airports could also benefit from the study.

## 1.4 Scope

The focus of this study was the UAS sightings which occurred between September 2016 and August 2019 in the U.S., especially those that occurred near airports in the National Plan of Integrated Airport Systems (NPIAS). This study examined UAS sightings which occurred during the three-year period after 14 CFR Part 107 Small Unmanned Aircraft Systems became effective on August 29, 2016.

There were four reasons that NPIAS airports were of interest to this study. In recent years, hundreds of NPIAS airports, especially primary airports, have been affected by UAS sightings. Between September 2016 and August 2019, 93.3 percent of UAS sightings were reported close to NPIAS airports, while NPIAS airports only accounted for 16.9 percent of airports in the U.S. (FAA, 2020a, 2018a).

Secondly, NPIAS airports were the most vulnerable to UAS sightings. UAS sightings at these airports could result in flight delays, flight diversion, temporary operational halts, and even airport shutdowns. The duration of a UAS sighting could range from a few minutes of holding flights over the airport in the traffic pattern to airport shutdown for dozens of hours.

As a result of the disruption to flights and airport operations, airports suffered from huge economic losses due to UAS sightings. When airlines cannot fly, airports can lose a variety of revenues, such as facility charges paid by passengers in their air tickets and the takeoff and landing fees paid by airlines (De Langhe et al., 2013).

In addition to the impacts of UAS sightings on airports, UAS were also a threat to both commercial and general aviation (GA) aircraft during all phases of the flight. Mid-air collisions of a UAS with human-piloted aircraft have occurred in the U.S., Canada, and Argentina, and have provided evidence that manned aircraft were vulnerable to UAS when they appear in the vicinity of airports (Hradecky, 2017; NTSB, 2017; Transportation Safety Board of Canada, 2018).

## 1.5 Assumptions

The assumptions of this study were:

1. There was a need to study the characteristics of UAS sightings, the impact of UAS sightings on airport operations, and the perspective of airport operators on UAS sightings.

2. The information contained in UAS sightings reports and other databases used in this study was accurate.
3. Interviewees answered interview questions accurately.

## 1.6 Limitations

The following are the limitations of this study of which readers should be aware.

1. The literature review was limited to materials available at Purdue libraries, online access, and inter-library loans.
2. The validity of this research study was limited by the truthfulness and accuracy of UAS sighting reports, FAA's public data, and interview responses.
3. The number of interviews was limited to airport directors, managers, and operational supervisors who could be reached and were willing to participate.
4. Perspectives and insights on UAS at airports were gained from interviewees working at airports.

## 1.7 Delimitations

The following are identified delimitations which affect the scope of this study.

1. The study focused on investigating UAS sightings. UAS accidents and incidents that resulted in injuries or aircraft damage were not studied.
2. UAS sightings that were reported between September 2016 and August 2019 in the U.S. were analyzed.
3. The UAS sighting which occurred at Newark Liberty International Airport (EWR) was studied to understand the impact of UAS sightings on airport operations.
4. Interview participants of this research only included those airport directors, managers, and operation supervisors who were willing to participate in this study.

# CHAPTER 2. REVIEW OF LITERATURE

This chapter provides an overview of relevant literature and prior research related to UAS and airports. It starts with a general introduction of regulations and legislation of sUAS, the NAS, and operations of sUAS in the NAS. Then this chapter discusses U.S. airports, ground stops, and flight delays, then compares the influences of nature-related and non-nature-related flight delays and airport shutdowns. Finally, UAS sightings at major airports and mid-air collisions involving UAS are presented.

## 2.1 Regulation and Legislation of sUAS

In February 2012, Congress enacted legislation that was designed to facilitate the commercialization and safety of UAS operations. Pursuant to the FAA Modernization and Reform Act (FMRA) of 2012, Congress directed the FAA to "produce comprehensive UAV regulations to safely accelerate the integration of civil unmanned aircraft systems into the national airspace system" (§ 332). In addition, the FMRA required the FAA to "implement a plan to integrate UAVs into the NAS by no later than September 30, 2015." The FAA released the first edition of *Integration of Civil Unmanned Aircraft Systems (UAS) in the National Airspace System (NAS) Roadmap* in 2013, which outlines the required actions and considerations to enable the integration of UAS into the NAS.

On August 29$^{th}$, 2016, 14 CFR Part 107 Small Unmanned Aircraft Systems became effective. This regulation addresses civil flights of UAS weighing between 0.55 and 55 lbs and focuses on three key aviation safety areas for sUAS: operations, personnel, and equipment. The regulation creates the Remote Pilot Certificate, which is an airman certificate of UAS and an individual is able to obtain the certificate by passing a knowledge test. Part 107 provides operators unprecedented access to the NAS while ensuring safety. However, this is the FAA's first step in its plan to integrate UAS into the NAS. Subsequent steps will facilitate transporting people and property by using UAS and operations beyond visual line of sight (VLOS) (FAA, 2018b).

Due to the increased availability and popularity of UAS, many states have passed legislation to address related concerns. As of December 2018, 41 states have enacted laws and regulations to address UAS-related issues, and there are another three states that have adopted resolutions (National Conference of State Legislatures, 2020). The privacy issue is one of the most important fields of legislation for UAS in the country (Essex, 2016). Thus, some states have considered legislation addressing privacy and UAS (Florida Department of Transportation, n.d.). In addition to the privacy concerns, common issues addressed in state laws include defining what a UAS is, how UAS can be used in hunting game, and regulations for their use by law enforcement, state agencies, and the general public.

While the majority of states have acted to handle various issues related to the privacy issue with UAS operations within their borders, the FAA has major responsibilities for providing guidance and regulations for operations and management of UAS, since the FAA focuses primarily on safety. The mission of the FAA (2019a) is "to provide the safest, most efficient aerospace system in the world," but this mission does not include regulating issues related to privacy. In addition, the matter of who controls the usage of airspace – what aviation authorities refer to NAS – is established as a matter of federal law. It is stated in 49 United States Code (U.S.C.) § 40103(a) (Sovereignty and Use of Airspace, 2011) that:

> The United States has sole and exclusive authority over its navigable airspace. The federal government controls the use of airspace pursuant to the Supremacy Clause of the Constitution, as further implemented through aviation laws and regulations that preempt state and private property laws.

## 2.2 National Airspace System

Within the NAS, there are four types of airspace: controlled airspace, uncontrolled airspace, special use airspace, and other airspace (FAA, 2016). The types of airspace depend on several factors: the density and complexity of aircraft movements, the required safety level, the types of aircraft operations conducted in the airspace, and national and public interests.

Controlled airspace is a generic term that "covers the different classifications of airspace and defined dimensions within which air traffic control (ATC) service is provided in accordance with airspace classification" (FAA, 2016, p. 15-2). Controlled airspace consists of Class A airspace, Class B airspace, Class C airspace, Class D airspace, and Class E airspace.

In contrast, uncontrolled airspace is known either by that term or as Class G airspace and represents "the portion of airspace that has not been designated as one of Class A, B, C, D, or E. Class G extends from the surface to the base of the overlying Class E airspace. Air traffic control has no authority or responsibility to control air traffic in Class G, but there are visual flight rules (VFRs) that apply" (FAA, 2016, p. 15-3).

In addition to controlled and uncontrolled airspace, the FAA (2016) also recognizes six types of "special use airspace." Special use airspace or "special area of operation" is designated as airspace where certain types of activity must be confined, or in which limitations may be imposed on aircraft operations that are not relevant to those activities. Special use airspace usually consists of prohibited areas, restricted areas, warning areas, alert areas, military operation areas, and controlled firing areas.

Finally, the FAA (2016) recognizes "other airspace area," a term refers to "the majority of the remaining airspace, including local airport advisories, military training routes, temporary flight restrictions, parachute jump aircraft operations, published VFR routes, terminal radar service areas, and national security areas."

## 2.3 Operations of sUAS in the NAS

The operations of sUAS are authorized in certain airspace, depending on operational type and type of aircraft. The FAA (2020b) classifies UAS operations into four types based on the operational purpose, including hobby or recreational, commercial, public, and educational operation. Figure 2.1 outlines the relationships between operation and aircraft types, and the relevant regulations, standards and airspace requirements, which apply to sUAS operations in controlled and uncontrolled airspace.

<table>
<tr><th colspan="2">Operation Type</th><th>Aircraft Type</th><th>Regulations and Standards</th><th>Airspace Requirements</th></tr>
<tr><td rowspan="3">Civil</td><td rowspan="2">Hobby/ Recreational/ Educational</td><td>Model</td><td>1. 14 CFR Part 101 (Moored Balloons, Kites, Amateur Rockets, Unmanned Free Balloons, and Certain Model Aircraft, 2017);<br>2. Section 336 of FMRA 2012; and<br>3. Advisory Circular 91-57B (FAA, 2019b).</td><td>Notify the airport operator and ATC tower to fly within five miles of an airport.</td></tr>
<tr><td rowspan="2">Non-model</td><td rowspan="2">14 CFR Part 107 (Small Unmanned Aircraft Systems, 2016).</td><td rowspan="2">Class B, C, D, E: ATC authorization required.<br>Class G: no authorization required.</td></tr>
<tr><td>Commercial (<55 lbs.)</td></tr>
<tr><td colspan="3">Public</td><td>1. 49 U.S.C. § 40102(a) (Definitions, 2011a) and § 40125 (Qualifications for Public Aircraft Status, 2000); or<br>2. 14 CFR Part 107.</td><td>Pursuant to Certificates of Waiver or Authorization, or Part 107.</td></tr>
</table>

Figure 2.1 Allowable operations for sUAS vary depending on the operation.

Many UAS are used as public aircraft. A public aircraft means an aircraft that is owned or operated by a governmental entity for certain governmental functions, such as national defense, intelligence missions, or aeronautical research (Definitions, 2011a). Civil aircraft includes all aircraft that are not public aircraft.

Model aircraft are one of the categories under civil aircraft carved out from certain regulatory requirements (Ravich, 2017). Model aircraft, which are also called recreational or hobby aircraft, mimic full-scale aircraft and helicopters in appearance and functionality. The FAA formally defined hobby aircraft as model aircraft used for recreational or sport purpose only. Thus, a model aircraft is "an unmanned aircraft that is: (i) capable of sustained flight in the atmosphere; (ii) flown within VLOS of the person operating the aircraft; and (iii) flown exclusively for hobby or recreational purposes" (Moored Balloons, Kites, Amateur Rockets, Unmanned Free Balloons, and Certain Model Aircraft, 2019).

In the FAA's 2015 Notice of Proposed Rulemaking **(**Operation and Certification of Small Unmanned Aircraft System), the agency proposed "limiting the exposure of small unmanned aircraft to other users of the NAS by restricting sUAS operations in controlled airspace." The notice articulated a prohibition of sUAS operations in Class A airspace, which begins at 18,000 feet and extends up to 60,000 feet mean sea level (Designation of Class A, B, C, D, and E Airspace Areas; Air Traffic Service Routes; and Reporting Points, 2017). The newly enacted Part 107 (Small Unmanned Aircraft Systems, 2016) did not adopt the proposed prohibition. Because sUAS are not able to access Class A airspace without violations of other Part 107 operational restrictions (Ravich, 2017). Under this regulation, sUAS operators are not allowed to operate small unmanned aircraft in Class B airspace, Class C airspace, or Class D airspace, or within "lateral boundaries of the surface area of Class E airspace designated for an airport," unless an ATC authorization has been issued to the operator before the flight. Part 107 allows unmanned aircraft operations in Class G airspace but includes a provision in its final rule that all of the sUAS operations that may impede traffic patterns or manned aircraft operations at airports, heliports, and seaplane bases are prohibited. This rule indicates the FAA's determination that operations of sUAS will be combined with operations of manned aircraft in Class G airspace.

In addition to the limitation on airspace, under Part 107 rules (Small Unmanned Aircraft Systems, 2016), sUAS operators must also do the following, although in some cases waivers have been granted by the FAA:

- Fly no higher than 400 feet above the ground,
- Keep aircraft within VLOS during daylight,
- Not exceed the ground speed of 100 miles per hour,
- Yield right of way to manned aircraft,
- Not fly from a moving vehicle unless in a rural area, and
- Fly during the day, or during twilight hours with anti-collision lights.

The FMRA of 2012 details five operational constraints that model aircraft operators must adhere to. For example, the regulation requires that the UAS operator must notify the airport operator and the airport traffic control tower prior to the operation when flying within five miles of an airport.

## 2.4 Airports in the U.S.

In 49 U.S.C. § 40102(2) (Definitions, 2011b), an airport is defined as "an area of land or water used or intended to be used for the landing and taking off of aircraft" and "an appurtenant area used or intended to be used for airport buildings or other airport facilities or rights of way." Airports are categorized based upon ownerships, importance, activity type, and number and percentage of annual passenger boarding. Figure 2.2 shows the categories of airports and the number of each type of airport in the U.S.

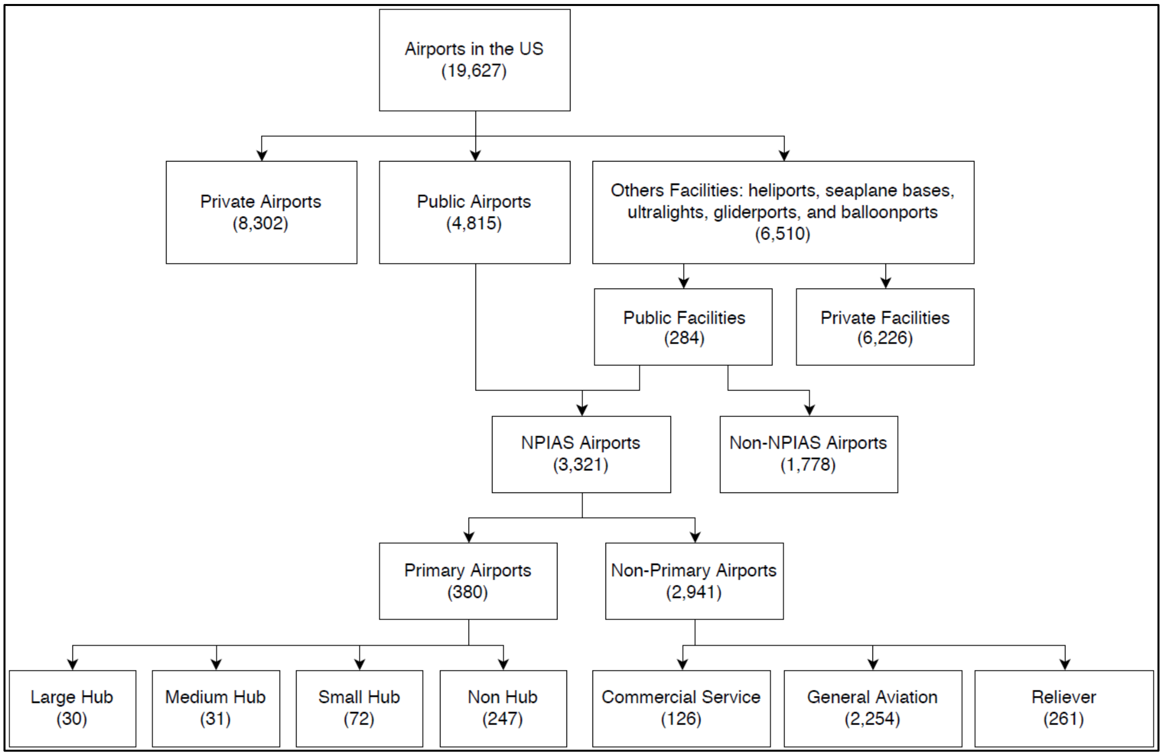



Figure 2.2 U.S. airport categories and numbers. (Source: FAA, 2018a)

According to the FAA (2018a), NPIAS airports are regarded as public-use airports that are important to the national airport system. NPIAS airports, which include primary airports and non-primary airports, are further defined and categorized based on airport activity types and annual passenger boarding. Primary airports are defined as “commercial service airports that have more than 10,000 passenger boardings each year” (Definitions, 2011b). Table 2.1 shows the definitions of primary airports by hub type, the percentage of each type of airport in NPIAS, and the percentage of these airports’ commercial enplanements in 2016 (FAA, 2020c, 2020d).

Table 2.1 Definition and statistics of primary airports.

| Hub Type | Examples | Number of Airports | Percentage of NPIAS Airports | Percentage of 2016 Total Commercial Enplanements | Percentage of Total Aircraft Operations | Percentage of NPIAS Costs | Definition |
|---|---|---|---|---|---|---|---|
| Large | LaGuardia Airport (LGA) | 30 | 0.9 | 72.48 | 13.1 | 23.5 | The annual passenger boarding at the airport is not less than one percent of total passenger boarding in the U.S. |
| Medium | Indianapolis International Airport (IND) | 31 | 0.9 | 15.87 | 4.9 | 10.5 | The annual passenger boarding at the airport is not less than 0.25 percent but less than one percent of total passenger boarding in the U.S. |
| Small | Long Beach Airport (LGB) | 72 | 2.2 | 8.21 | 6.9 | 11.9 | The annual passenger boarding at the airport is not less than 0.05 percent but less than 0.25 percent of total passenger boarding in the U.S. |
| Non-hub | Evansville Regional Airport (EVV) | 247 | 7.4 | 3.26 | 10.7 | 15.2 | The annual passenger boarding at the airport is not less than 10,000, but less than 0.05 percent of total passenger boarding in the U.S. |
| Primary Total | | 380 | 11.4 | 99.83 | 35.6 | 61.1 | |

As shown in Table 2.1, large hub, medium hub, small hub, and non-hub airports account for only 11.4 percent of NPIAS airports, however, these airports accounted for 99.83 percent of commercial enplanements in 2016, 35.6 percent of aircraft operations, and 61.1 percent of NPIAS airport development costs. Therefore, it is valuable to focus on these primary airports to ensure that future UAS mitigation efforts are directed to airports where they will have the greatest impact.

## 2.5 Ground Stops and Flight Delays

A UAS sighting in the vicinity of an airport can cause flight delays, flight diversions, temporary operational halts, and even airport shutdowns. A temporary operational halt at the airport is designated as a ground stop. The following section explains the ground stops and flight delays in greater detail.

### 2.5.1 Ground Stops

A ground stop is a process that requires aircraft to remain on the ground when the aircraft meet the specific criteria associated with the airport, airspace, or equipment (FAA, 2017b). Ground stops can be implemented for a variety of reasons (Air Traffic Control System Command Center [ATCSCC], n.d. -a). The most common reasons to implement a ground stop are: to stop traffic temporarily in order to allow a longer-term solution to be implemented, to control an airport's air traffic volume when the airport's predicted demand for air traffic is forecasted to outpace its acceptance rate for a short period of time, and because the acceptance rate of the affected airport has been reduced to zero. Ground stops are also used when a facility is unable or partially unable to perform ATC services as a result of unforeseen circumstances, and when routings are unavailable due either to severe weather or other catastrophic events.

According to the FAA's (2009) rules, airports may implement an internal ground stop for up to 30 minutes. Once the ground stop is expected to last 15 minutes or more, the ATCSCC is notified and given control of the situation, including the option to extend the ground stop and expand its scope. If the ground stop is expected to last for more than 30 minutes, an advisory is issued by the ATCSCC informing passengers of the extension. In many cases, it is not immediately clear for how long a ground stop will last when it is issued.

During the January 2019 UAS sighting at EWR, FAA executed a ground stop after receiving reports of the UAS sighting from pilots, as they believed that the airport would be unable to perform ATC services because of the disruption caused by the UAS. Since the ground stop lasted for only 21 minutes (Shepardson, 2019), passengers were not notified of it.

### 2.5.2 Flight Delays

There are 18 U.S. air carriers which report their data for flight delays to the Bureau of Transportation Statistics (Bureau of Transportation Statistics [BTS], 2017) every month. The causes of the delays that are reported by air carriers are classified into five broad categories:

- Air carrier delays, caused by circumstances within the airline's control, such as maintenance issues and aircraft cleaning.
- Extreme weather delays resulted from significant actual or forecasted meteorological conditions, including tornadoes, blizzards, or hurricanes.
- National airspace system delays, which include all delays that are attributed to the national aviation system, such as airport operations, heavy volume of air traffic, and non-extreme weather conditions.
- Late-arriving aircraft delays, defined as late departures of present flights which are caused by late arrivals of previous flights when both flights use the same aircraft.
- Security delays resulted from the aircraft re-boarding due to a security breach, the evacuation of terminal(s) or concourse(s), ineffective screening equipment, or more than 29 minutes' long lines at screening areas.

### 2.5.3 Data on Ground Stops and Flight Delays

Although air traffic delays and ground stops always present inconveniences for travelers, the ATCSCC's website and operational information system (OIS) provide accurate, up-to-the-minute flight delay information for most large hub airports and many medium hub airports in the U.S. In addition to flight-specific information, the website offers information concerning general airport conditions. Figure 2.3, for instance, shows the delay status of each major airport on December 1$^{st}$, 2019, 10:02 a.m. coordinated universal time (UTC).


Figure 2.3 Delay status of major U.S. airports on December 1st, 2019, 10:02 a.m. UTC. (Source: ATCSCC, n.d. -b)

Different flight delay statuses are represented in different colors (ATCSCC, n.d. -c): green indicates that general arrival and departure delays are 15 minutes or less; yellow means that departures are subject to taxi delays of 16 to 45 minutes and/or arrivals are subject to airborne holding delays of 16 to 45 minutes; orange indicates that traffic destined to this airport is being delayed at its departure point and passengers are recommended to check the status at their departure airport to determine if their flights may be affected; finally, red means that departures and/or arrivals are subject to delays greater than 45 minutes. At the time represented on the map, a traffic management program, resulting from snow and ice, was affecting the arriving traffic at EWR. The airport's arrival flights were experiencing an average of two hours and 33-minute delays, as can be seen in the real-time status information for the airport shown in Figure 2.4.

Newark International Airport (EWR) Real-time Status

The status information provided on this site indicates general airport conditions; it is not flight-specific. Check with your airline to determine if your flight is affected.

Due to **WEATHER / SNOW-ICE**, there is a Traffic Management Program in effect for traffic arriving **Newark International Airport, Newark, NJ (EWR)**. This is causing some arriving flights to be delayed an average of **2 hours and 33 minutes**. To see if you may be affected, select your departure airport and check "Delays by Destination".

**Delays by Destination:**

- Due to WEATHER / SNOW-ICE, departure traffic destined to **CYYZ airport** is currently experiencing delays averaging **3 hours and 18 minutes**.
- Due to WEATHER / SNOW-ICE, departure traffic destined to **La Guardia Airport, New York, NY (LGA)** is currently experiencing delays averaging **1 hour and 4 minutes**.
- Due to WEATHER / WIND, departure traffic destined to **San Francisco International Airport, San Francisco, CA (SFO)** is currently experiencing delays averaging **4 hours and 32 minutes**.

**General Departure Delays:** Because a traffic management program is delaying some arriving flights, departing flight schedules may be affected. Check with your airline to determine if your flight is affected.

**General Arrival Delays:** Arrival traffic is experiencing airborne delays of 15 minutes or less.

Figure 2.4 Real-time status at EWR. (Source: ATCSCC, n.d. -d)

Delay information for each airport, which is received from FAA facilities, is available via the ATCSCC OIS (n.d. -a). The system provides ground stop, deicing, runway, and equipment information, as well as general information concerning airport delays and closures. Figure 2.5 shows information for a ground stop at Chicago O'Hare International Airport (ORD).

| ARPT | UPDATE | POE | SCOPE | REASON | ADVZY |
|---|---|---|---|---|---|
| ORD | 1700 | LOW | ZAU1 | SNOW REMOVAL | 12 |

Figure 2.5 Information for a ground stop at ORD. (Source: ATCSCC OIS, n.d. -b)

As shown in Figure 2.5, flights destined for ORD that are departing from airports under the jurisdiction of the Chicago Air Route Traffic Control Center (ARTCC) and Chicago's first tier ARTCCs (ZAU1) have been stopped. The ground stop has been implemented because snow is being removed from the Chicago airport's runways; it is expected to end at 5:00 p.m. UTC and the probability of extension (POE) is low. During the event, the ATCSCC also issues a corresponding advisory (ADVZY) to this ground stop.

## 2.6 Comparison of Nature-related and Non-nature-related Delays and Airport Shutdowns

This subsection presents various causes of airport shutdowns, categorizing them into those caused by natural and non-natural circumstances; it then evaluates the similarities and differences between the impacts of delays and airport shutdowns with natural and non-natural causes.

### 2.6.1 Causes of Airport Shutdowns

There are various scenarios that could result in the shutdown of an airport. In general, airport closures can be categorized as either long-term or short-term closures (Rupp & Holmes, 2006). Long-term closures are typically provoked by circumstances that are strictly economic and therefore strategic. However, most closures of airports are relatively short-term closures, which can be further categorized as nature-related short-term closure and non-nature-related short-term closure (Rupp et al., 2005). Nature-related airport closures include those initiated by bad weather conditions, such as volcanic eruptions (Wilson et al., 2014), hurricanes (FAA, 2018c), heavy snowfall (Mezzofiore, 2019), and haze (Lee et al., 2012). Non-nature-related airport closures, by contrast, are caused by occurrences such as UAS sightings (Silk, 2019), shortages of air traffic controllers (Davis, 2019), power outages (Gold & Carey, 2017), runway excursions (Mohney et al., 2015), terrorist attacks (Gordon et al., 2007), or bomb scares ("Atlanta Airport Shutdown," 2006).

### 2.6.2 Similarities between Nature and Non-nature Related Delays and Shutdowns

When ground traffic, departures, or approaches at a specific airport are halted due to any irregularity, arriving traffic is diverted to alternate airports or kept airborne until the aircraft can safely land; departures, meanwhile, are held on the ground and new departure slots are assigned, while flights that are destined for the closed airport but have not yet departed are grounded (Pejovic et al., 2009). Figure 2.6 illustrates the effects an airport shutdown has on flights destined for that airport. These effects are the same regardless of whether the shutdown is caused by natural or non-natural events.

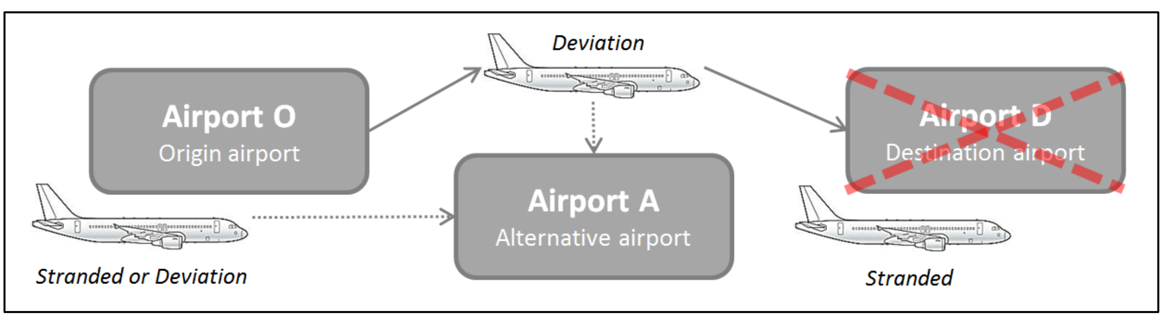



Figure 2.6 Effects of the shutdown of destination airport on flights. (Source: De Langhe et al., 2013)

Shutdowns at a particular airport (due to either natural or non-natural causes) often cause delays at other locations (Welman et al., 2010). A study by Allan et al. (2001) found that exceptional events affecting New York area airports can create serious disturbances in traffic flow that are felt throughout the NAS.

When irregularities occur for any reason, airports often need to call upon additional resources in order to resume normal operations, which may result in additional operational expenses (Wong & Tsai, 2012). However, airports often lack the necessary supplies in the short run for exogenous reasons (Rupp & Holmes, 2006). As shutdowns cannot be planned in advance, this means that airports frequently have only general measures at their disposal to deal with the consequences of the shutdown, regardless of its cause.

### 2.6.3 Differences between Nature and Non-nature related Delays and Shutdowns

One difference between delays and airport shutdowns caused by nature-related events and those with non-nature-related causes is that the former can partly be forecasted, allowing airports to take certain preventive measures, while non-nature-related shutdowns are often difficult to predict or anticipate (Rupp et al., 2005).

Nature-related and non-nature-related airport shutdowns also tend to result in different airport capacity levels after the airport reopens (Rupp et al., 2005). Immediately following a nature-related shutdown, the majority of the airports operate for a period of time at a capacity level that is lower than normal operations; following a non-nature-related shutdown, however, most airports return quickly to operating at full capacity.

A third difference between the impacts of the two types of shutdowns concerns the way the effects of the shutdown are distributed geographically (Rupp et al., 2005). Shutdowns caused by natural conditions are typically concentrated among airports in a particular region, while those caused by non-natural circumstances tend to affect airports that are geographically scattered.

## 2.7 UAS Incidents at Major Airports

As numerous events have demonstrated, the incursion of UAS into airport spaces can have chaotic effects and disrupt airport operations. Several incidents involving UAS-related disruptions at major airports around the world have drawn widespread attention among the public and been the subject of reporting in numerous media outlets. Table 2.2 summarizes the UAS sightings at large airports worldwide between 2017 and 2018.

Table 2.2 UAS sightings at large airports, September 2018 – August 2020.

| Event Date | Airport | Location | Impacts of the UAS Sighting on the Airport and Flights | Airport Annual Enplanements |
|---|---|---|---|---|
| November 11, 2018 | Wellington Airport | Wellington, New Zealand | The airspace around the airport was closed for 30 minutes (Gudsell, 2018). | 6.1 million passengers in 2018 (Wellington Airport, 2019) |
| December 19 to 21, 2018 | Gatwick Airport | Horley, U.K. | The airport was closed for 33 hours; about 1,000 flights were diverted or canceled; around 140,000 passengers were affected (Yeginsu, 2018) | 46.6 million passengers in 2019 (CAA, 2020) |
| January 8, 2019 | Heathrow Airport | Longford, U.K. | The departing runway was closed for an hour (Martin, 2019). | 80.9 million passengers in 2019 (CAA, 2020) |
| January 22, 2019 | Newark Liberty International Airport | Newark, New Jersey | Inbound traffic was halted for 21 minutes; 43 flights were holden in the air; nine flights were diverted (Shepardson, 2019). | 46.3 million passengers in 2019 (The Port Authority of NY and NJ, 2020). |
| February 15, 2019 | Dubai International Airport | Dubai, U.A.E. | Flight departures were suspended for 30 minutes (Wolgelenter, 2019). | 86.4 million passengers in 2019 (Dubai Airports, 2019) |
| March 22, 2019 | Frankfurt Airport | Frankfurt, Germany | Air traffic was halted for 30 minutes (GardaWorld, 2019). | 70.6 million passengers in 2019 (Fraport, 2020) |
| April 28, 2019 | Gatwick Airport | Horley, U.K. | Three flights were diverted (Forrest, 2019). | 36.9 million passengers in 2019 (CAA, 2020) |
| May 9, 2019 | Frankfurt Airport | Frankfurt, Germany | The airport was closed for an hour; more than one hundred flights were canceled (Lomas, 2019). | 70.6 million passengers in 2019 (Fraport, 2020) |
| June 18, 2019 | Singapore Changi Airport | Singapore | A runway was shut down for 10 hours; 37 flights were delayed; one flight was diverted (Yu, 2019). | 68.3 million passengers in 2019 (Changi Airport Group, 2020) |
| July 12, 2019 | Leeds Bradford Airport | Leeds, U.K. | The airport was closed for 45 minutes; flights were diverted to another airport ("Flights Diverted as Drone Sighted", 2019). | 3.7 million passengers in 2019 (BURLEY & MENSTON Airport discussion, 2020) |
| September 22, 2019 | Dubai International Airport | Dubai, U.A.E. | Arrivals were disrupted for about 15 minutes; two flights were diverted ("Two Flights diverted from Dubai", 2019). | 86.4 million passengers in 2019 (Dubai Airports, 2019) |
| November 28, 2019 | Sharjah International Airport | Sharjah, U.A.E. | The airspace around the airport was closed; eight flights were diverted (Shurafa, 2019). | 13.6 million passengers in 2019 (Sharjah Airport, n.d.) |
| December 24, 2019 | Muscat International Airport | Muscat, Omen | The airport was closed for 90 minutes; a number of flights were delayed or diverted ("Drones disrupt flight operations", 2019). | 12.9 million passengers in 2018 (Muscat International Airport, 2019) |
| February 2, 2020 | Madrid Barajas International Airport | Madrid, Spain | The airport was closed for over an hour; 26 flights were diverted ("Drone Sighting Disrupts Air Traffic", 2020). | 61.7 million passengers in 2019 (Aena, 2020) |
| March 2, 2020 | Frankfurt Airport | Frankfurt, Germany | The airport was closed for two hours; multiple flights were canceled, delayed, or diverted (Hollan, 2020). | 70.6 million passengers in 2019 (Fraport, 2020) |

As shown in Table 2.2, the incursion of a UAS into the airport space can disrupt airport operations, result in delayed, canceled, or diverted flights, and may lead to economic loss for the airports, commercial carriers, and cargo transport. Four of these incidents are discussed in the following sections.

### 2.7.1 Gatwick Airport

A series of UAS sightings were reported at Gatwick Airport between December 19th and December 21st, 2018, which caused significant disturbances for the aviation industry in the U.K. UAS sightings at Gatwick disrupted about 1,000 flights carrying 140,000 passengers and provoked the 36-hour shutdown of England's second-busiest airport (Yeginsu, 2018).

The shutdown was initiated just after 9:00 p.m. local time on December 19th, 2018, when two UAS were found flying into the airside of the airport ("Gatwick Airport," 2018). Gatwick's runway briefly reopened at 3:01 a.m. on December 20th, but it was closed again approximately 45 minutes later following another UAS sighting. At 10:20 a.m., Sussex Police determined that the event was not related to terrorism, but was the result of an attempt to disrupt flights using "industrial specification" UAS (Evans et al., 2018). At 9:35 p.m. that day, the Detective Chief Superintendent of Sussex Police said that reports of more than 50 UAS sightings had been made by members of the public, passengers, police officers, and airport staff members in the preceding 24 hours. The airport remained closed until 6:14 a.m. on December 21st, at which time the runway was opened to a limited number of flights. Hence, the airport warned passengers that the disruption could last several days and advised them not to travel to the airport without checking the status of their flight first (Morris, 2018). At 5:10 p.m., the runway was closed following another suspected UAS sighting, before being reopened at around 6:15 p.m. (Calder, 2018).

During the shutdown, a number of flights bound for Gatwick were diverted to other airports, including seven to Luton, 11 to Stansted, and five to Manchester. Some flights originally bound for Gatwick also landed at Cardiff, Birmingham, and Southend, while others were diverted to Heathrow, Glasgow, Paris, and Amsterdam ("Gatwick Airport," 2018). According to reports from the airport, approximately 10,000 passengers scheduled to fly or arrive on the night of December 19th were affected by the shutdown, while around 110,000 were affected the following day. In addition to those passengers whose flights to or from Gatwick were canceled, hundreds of passengers were scattered to distinct destinations across the country since their flights were forced to divert (Morris, 2018). Gatwick Airport reported that 160 of 837 scheduled flights on December 21st were ultimately canceled, but that the majority of the 126,000 passengers who booked flights departing from Gatwick Airport were able to travel to their destinations as planned (Topham, 2018). Due to the displacement of crews and aircraft that resulted from the above disruptions, some scheduled flights were also delayed on December 22nd (Evans at al., 2018). Ultimately, the CAA (2018b) stated that “it considered the event to be an extraordinary occurrence, and airlines were therefore not obligated to pay any financial compensation to affected passengers.”

Besides causing widespread flight disruptions, the UAS sightings at Gatwick Airport resulted in considerable economic losses for airlines and the airport. EasyJet, the largest air carrier at Gatwick, reported that flight disruptions related to the incident cost the company £15 million (equivalent to $20 million), including £5 million in lost revenues and £10 million in customer welfare costs, as many travelers canceled their flights after the shutdown was reported (Kollewe & Topham, 2019). Since EasyJet accounts for around 40 percent of flights at Gatwick Airport, assuming the airline’s financial losses from the incident to be proportional to those suffered by other airlines yields estimates of the total financial damage done to airline carriers between £35 million and £40 million (Calder, 2019; Tobin & Prynn, 2019).

Gatwick Airport lost millions of pounds in potential revenue as a result of the disruption. According to the latest annual reporting, the airport’s parent company yields roughly £400 million in revenue per year from passengers that take off and land at the airport (Petroff, 2019). This means that the airport generates approximately £1.1 million in aeronautical revenue per day on average. This value is close to the estimate provided by the director of the UK-based consulting firm JG Aviation Consultants, who stated that Gatwick Airport generates around £2.1 million in revenue on an average day, of which approximately 52 percent (£1.05 million) consists of direct aeronautical revenues charged to the air carriers (Christian, 2019). Since airlines during the December 2018 incident had little ability to accommodate passengers by putting them on later flights just days before Christmas, a considerable portion of the airport’s anticipated aeronautical revenue was lost. Revenue from duty- and tax-free sales was also severely impacted. Based on the airport’s March 2018 year-end reporting that revenues from such sales averaged around £147,000 per day, the total revenue loss as a result of the incident for duty- and tax-free shops can be estimated at £220,000.

In total, the losses for the aviation business resulting from the UAS sightings at Gatwick Airport were estimated to be between £50 million and £70 million (Calder, 2019), and the spokesperson from the CAA confirmed that the overall economic impact of the incident was significant (Petroff, 2019). Moreover, the incident revealed how vulnerable the U.K. airport system was to disruption and even attacks through the use of UAS (Britton & Clarke, 2018).

### 2.7.2 Heathrow Airport

On January 8th, 2019, three weeks after the Gatwick event, a similar incident occurred at London's Heathrow Airport, the main port of entry and exit for the U.K. and the busiest travel hub in Europe (Thuburn, 2019). At about 5:05 p.m. local time, London's Metropolitan Police announced that they had received reports of a UAS sighting "in the vicinity of Heathrow airport," at which point the airport halted all outbound flights for nearly an hour as a precautionary measure to prevent any threats to operational safety. During the temporary stoppage, one of the runways was closed as airport officials worked with the London Metropolitan Police to investigate the report (Rawlinson, 2019). Arriving flights were able to land, but some were diverted to other airports, including Stansted Airport, Luton Airport, and Manchester Airport (Quach, 2019). At around 6 p.m., the runway was reopened. British Airways, the largest carrier operating at Heathrow, had at least 40 flights delayed by half an hour or more after missing their departure slots, but the airline confirmed that none of its flights were canceled due to the UAS sighting (Ward et al., 2019).

### 2.7.3 Newark Liberty International Airport

On the evening of January 22, 2019, airline pilots reported a UAS in their approach path to EWR, which led the FAA to stop air traffic for 21 minutes (Shepardson, 2019; Silk, 2019). According to FAA spokesman Greg Martin, the agency received two reports of UAS operating near EWR at 4:44 p.m. (Aratani, 2019; Cohen, 2019). One Southwest Airlines pilot and another United Airlines pilot saw what they believed to be a UAS about 3,500 feet in the air above Teterboro Airport (TEB), New Jersey, as they were preparing to land their aircraft at EWR. An air traffic controller who watched over EWR airspace also spotted two UAS flying dangerously close to a plane ("FAA Investigating Drone Scare", 2019). Based on the reports, inbound flights to EWR were held in the air and takeoffs were momentarily stopped as a precaution (Dow, 2019). In total, the FAA held 43 inbound flights in the air, while ten were diverted to land at other airports. Another 170 planes bound for EWR were briefly delayed on the ground before taking off from other airports around the country. The EWR stoppage marked the first and only shutdown at a major U.S. airport due to an unauthorized UAS. The stoppage was relatively brief, and it only caused an average delay of approximately one hour, however, it provides an excellent example of potential for disruption, which motivates an investigation of the potential impact of UAS sightings on airports.

#### 2.7.4 Dubai International Airport

Following the above-mentioned UAS sightings in the U.K. and the U.S., UAS activity has become an increasing source of worry for airport administrators all over the world. Dubai International Airport (DXB), however, has been affected by unauthorized UAS activities multiple times in the past several years. A suspected UAS sighting briefly disrupted flight departures from the airport on February 15$^{th}$, 2019 (Porter, 2019), when the airport was shut down from 10:13 a.m. to 10:45 a.m. local time. It was estimated that departures were delayed by up to an hour due to the shutdown, though the incident had no impact on arrivals (Nasseri, 2019). An official later reported that the incident was provoked by an individual operating a UAS in a nearby desert (Dobush, 2019). The resulting disruption was relatively brief, but given that DXB is the third busiest airport in the world, even short delays can cause considerable problems.

This was not the first time that operations at DXB were disrupted by UAS activity. In January 2015, air traffic was halted when several individuals recklessly flew recreational UAS into the air navigation passages of planes (Mutzabaugh, 2015). The airport’s air traffic was suspended from 3:00 p.m. to 3:55 p.m. Some inbound flights were diverted to Al Maktoum International Airport, another airport in Dubai. In June 2016, the airport was again closed to aircraft from 11:36 a.m. to 12:45 p.m. due to reports of UAS activity (Remeithi, 2016), and 21 flights were diverted to three nearby airports, including 13 flights conducted by Emirates. A few months later, in September of the same year, the airspace around DXB was closed from 8:08 a.m. to 8:35 a.m. following another UAS sighting, resulting in delays to 90 flights (Debusmann, 2016; Pennington, 2016). Then in October, DXB and Sharjah International Airports were both closed for more than an hour each when a UAS intruded into the airspaces of the two airports. The airspace around Dubai was closed from 7:25 p.m. to 8:45 p.m., forcing the diversion of 22 inbound flights. The closure at Sharjah, meanwhile, began around 8 p.m., and flights were cleared to take off again at 9 p.m. Since the airport shares flight paths with Dubai, eight flights were affected at Sharjah Airport.

According to the Emirates Authority for Standardisation and Metrology, airports in the U.A.E. suffer direct financial losses of $95,368 for each minute that DXB is shutdown due to unauthorized UAS activity (Deulgaonkar, 2017). The total losses sustained as a result of the three events in 2016 were therefore estimated to be $16.62 million.

Per the UAS sighting events discussed above, many large airports have been affected by UAS sightings in recent years. Hence, UAS sightings in the vicinity of busy commercial airports is a severe threat that must be investigated as a top priority.

## 2.8 Manned Aircraft Accidents Involving UAS

UAS sightings close to airports have proven a threat to busy airports with the possibility of negative operational and economic impacts. In addition to the impacts of UAS sightings, UAS is a threat also to aircraft during all phases of the flight. There have been several mid-air collisions of a UAS with human-piloted aircraft.

### 2.8.1 Mid-Air Collision in the U.S.

The first confirmed mid-air collision between a manned aircraft and a UAS in the U.S. occurred on September 21$^{st}$, 2017, in Hoffman Island, New York (Lowy, 2017). A U.S. army UH-60M helicopter and a DJI Phantom 4 sUAS were involved in the accident (NTSB, 2017). At the time when the accident occurred, there was an effective temporary flight restriction, which covered the location where the accident occurred. The helicopter was authorized to fly under VFRs within Class G airspace at 274 feet in the temporary flight restriction area, while the UAS was not allowed to fly in the same area. The collision caused a dent on the leading edge of one of the helicopter's main rotor blades, and cracks in composite fairing and window frame material. The UAS was shredded in the collision, and some of the components were lodged in the helicopter (Wright, 2017).

According to the NTSB's (2017) report, the helicopter co-pilot was operating the aircraft when the collision occurred. When the UAS suddenly came into the co-pilot view in close proximity to the helicopter, the pilot reduced the collective pitch immediately and rapidly. Thereafter, the pilot-in-command took the controls and flew back to the base. The helicopter, which carried four crew members, landed safely. After landing, the air mission commander reported the accident to EWR's air traffic control tower.

The report (NTSB, 2017) indicates that the UAS operator flew the sUAS beyond VLOS, and therefore did not know the proximity of the helicopter. Although the UAS operator indicated that he knew helicopters frequently flew in the area, he still flew his UAS a distance of 2.5 miles away, which shows his lack of understanding of the danger of flying UAS in unauthorized areas and the potential hazard of collisions between UAS and other aircraft. In addition, the operator was unaware that his UAS had collided with the helicopter before being contacted by the NTSB.

### 2.8.2 Mid-Air Collision in Canada

On October 12$^{th}$, 2017, a Beechcraft King Air A100 aircraft was hit by a UAS near Québec City Jean Lesage International Airport (Transportation Safety Board of Canada, 2018). There were two pilots and six passengers on board. As the aircraft approached the airport, the aircraft was cleared for a visual approach to runway 24. During the final approach, the flight crew observed a UAS, about the size of a dinner plate, in front of the left-wing. However, the pilots had no time to take evasive actions. The collision took place at an altitude of 2,500 feet above sea level, and approximately seven nautical miles from the midpoint of runway 24. Two minutes after the collision, the flight crew declared an emergency, then completed the landing without further incident. There were no injuries in this incident. Nevertheless, the collision caused damage on the left-wing of the aircraft, including a dent at the point of impact on the left-wing de-icing boot and scratches on the upper surface of the left-wing.

### 2.8.3 Mid-Air Collision in Argentina

On November 11$^{th}$, 2017, an Aerolineas Argentinas Boeing 737-800 was struck by a UAS on its final approach to Aeroparque Jorge Newbery in Buenos Aires. The plane was flying over the Tierra Santa theme park when the accident occurred, as the crew observed the UAS and felt the impact of its collision at about 220 feet above ground level (Hradecky, 2017). The UAS struck the plane below the window on the captain's side. The plane completed its landing safely with no reported injuries, but the aircraft sustained minor damage on the angle of attack sensor. After landing, the captain notified the airport's control tower that a major incident had been averted (Kesteloo, 2017).

In the accidents described above, there were no injuries and only damage to aircraft was sustained. However, flying UAS near an airport or within controlled airspace brings serious risks to aviation safety. Both manned aircraft and airports are vulnerable to UAS when UAS appear around airports or fly beyond VLOS. For safety, it is important and necessary to analyze how unauthorized UAS operations can affect airports.

## 2.9 Summary

Chapter 2 presented the review of literature, which provided an important context for the proposed research and validated the need for further investigation of the threats of UAS sightings near airports. First, an overview of federal and state regulations that are related to sUAS was provided, including FMRA of 2012, 14 CFR Part 107, and examples of relevant state laws. Second, four categories of airspace in the NAS were explained, followed by airspace requirements of sUAS operations. Next, airport categories, as well as and their definition and statistics were reviewed. Then delays, shutdowns, and comparisons nature-related and non-nature-related delays and airport shutdowns were discussed. Finally, UAS sightings and mid-air collisions involving UAS were presented. The next chapter outlines the methodology used for this research.

# CHAPTER 3. METHODOLOGY

This chapter presents the methodology, including the research design, data sources, data collection procedures, and data analysis methods. Potential threats to research validity and strategies for ensuring research validity are also discussed.

## 3.1 Research Design

This study used a mixed-method research methodology, which was described by Creswell (2014) as follows:

> An approach to research… in which the investigator gathers both quantitative and qualitative data, integrates the two, and then draws interpretations based on the combined strengths of both sets of data to understand research problems (p. 2).

This research included three primary components: the analysis of FAA's UAS sighting reports, a case study on EWR UAS sighting, and interviews. In this study, UAS sighting reports were studied in both qualitative and quantitative ways. The FAA's Operations Network (OPSNET) data and Aviation System Performance Metrics (ASPM) data were analyzed and illustrated for the UAS sighting that occurred at EWR. Qualitative analysis was conducted based on interview results. Figure 3.1 shows the structure of the study.

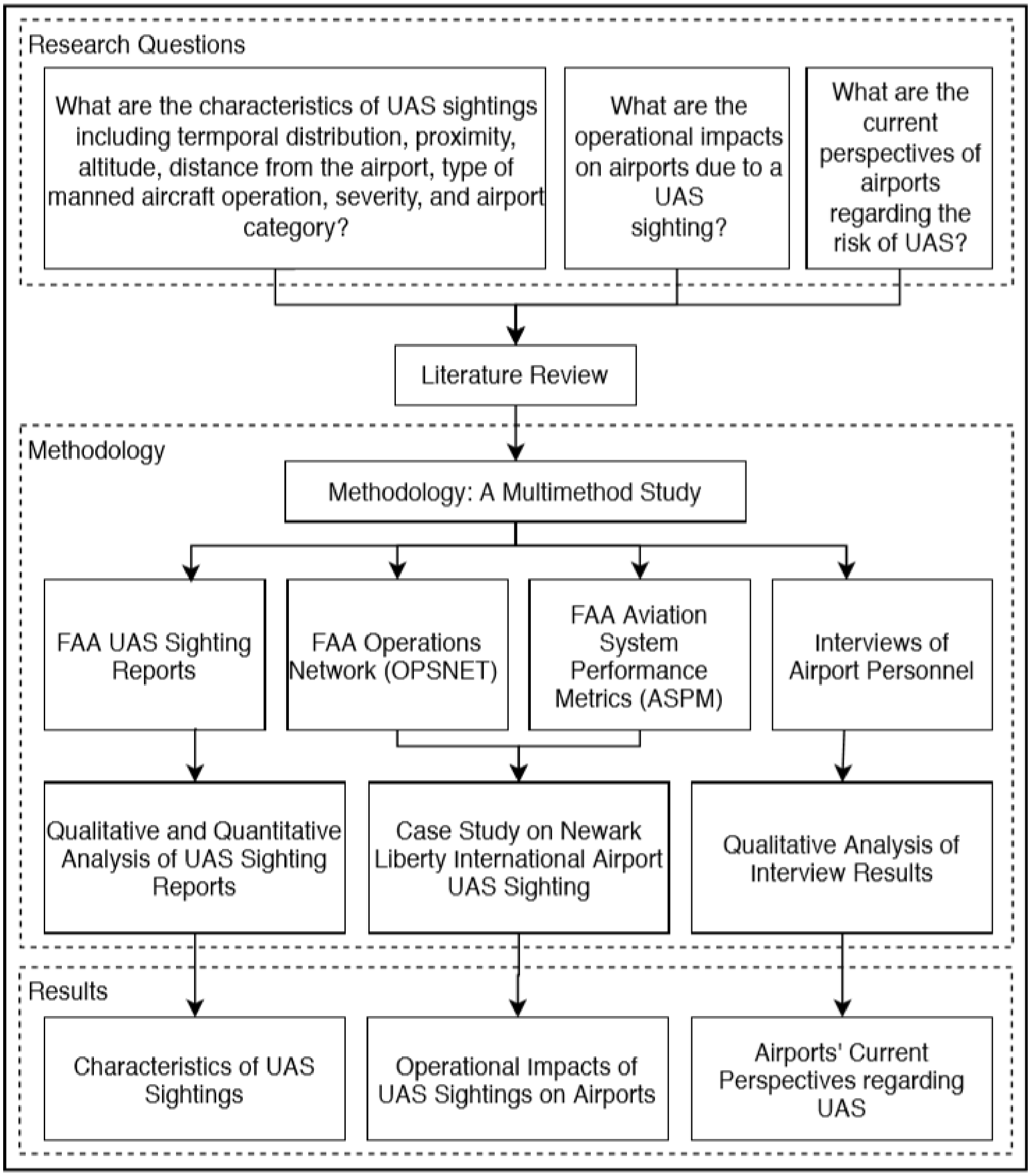



Figure 3.1 Research structure of this study.

## 3.2 Data Sources and Data Collection Procedures

Data that were used in this study came from four sources, including the FAA's UAS sighting reports data, OPSNET data, ASPM data, and results from interviews of airport personnel.

### 3.2.1 UAS Sighting Reports

The UAS sighting reports analyzed in this study were obtained from the FAA's UAS sighting reports data, which have been collected by FAA (2020a) since November 2014. As of July 1st, 2020, the FAA released 9,968 reports for UAS sightings between November 2014 and March 2020. Because 14 CFR Part 107 officially went into effect on August 29, 2016, this study examined UAS sightings occurred during the three-year period September 2016 to August 2019.

The UAS sighting reports are available to the public, and reflect reports submitted by commercial and GA pilots, air traffic controllers, citizens, and law enforcement officers (LEO) (Gettinger & Michel, 2015). UAS sighting reports generally provide information about the sighting date, time, city, state, and a narrative of the event. For each UAS sighting, the narration contains the following information:

- The source of the UAS sighting report,
- The altitude of UAS,
- The distance from UAS sighting location to the nearby airport,
- Nearby airport,
- Whether a mandatory occurrence report (MOR) alert was issued,
- Law enforcement department(s) who was notified of the UAS sighting,
- The model of manned aircraft,
- The proximity of UAS to manned aircraft,
- The distance between UAS and manned aircraft, and
- Whether evasive action was taken by the pilot(s) of the manned aircraft.

A sample of a UAS sighting report is shown in Appendix A.

### 3.2.2 Case Study

The FAA's OPSNET data and ASPM data were used to study the impact of the UAS sighting at EWR. The OPSENT and the ASPM are two of the FAA's operations and performance data access systems (FAA, n.d. -a).

#### 3.2.2.1 Operations Network Data

The FAA maintains the OPSNET database and uses the data to produce operational metrics and improve FAA efficiency (FAA, 2015). The OPSNET data includes traffic operations and reportable delays. The following eight categories of data and information is available on the OPSNET (FAA, n.d. -b, n.d. -c):

- Airport operations dataset: departures and arrivals at FAA-funded airports, including itinerant instrument flight rule (IFR) and VFR operations, and local operations.
- Tower operations dataset: take-offs, landings, and other aircraft operations worked by airport traffic control towers, including itinerant and overflight IFR and VFR operations, and local operations.
- Terminal radar approach control (TRACON) operations dataset: itinerant IFR and VFR operations at all airports and overflights worked by the TRACON.
- Total terminal operations dataset: total traffic worked at all facilities; this reflects the total of the TRACON operations and airport traffic control tower operations.
- Center aircraft handled dataset: total aircraft operations handled by Center Radar Approach Controls and ARTCCs.
- Facility information dataset: information about ATC facilities, such as a facility's type, name, state, region, and operational hours.
- Delays dataset: data about reportable delays. The OPSNET delays are counted when a flight is delayed for more than 15 minutes compared with its original flight plan which is filed with the FAA (2017c). The OPSNET delays can be categorized according to cause into the following categories: weather, traffic volume, equipment, runway, and other.
- Other reports dataset: customized reports for internal FAA customers.

In this study, the researcher obtained data associated with the EWR UAS sighting from the airport operations dataset and delays dataset.

#### 3.2.2.2 Aviation System Performance Metrics Data

Aviation System Performance Metrics is an online database with flight data for selected airports and the ASPM carriers. The ASPM carriers include domestic scheduled carriers, as well as FedEx, UPS, and Air Canada (FAA, n.d. -d). There are 77 ASPM airports in the U.S, including the Core 30 airports, the Operational Evolution Partnership 35 airports, and another 42 airports (FAA, n.d. -e). The Core 30 airports are 30 large hub airports in the U.S. (FAA, n.d. -f). The Operational Evolution Partnership 35 airports include all large hub airports and five medium hub airports (FAA, n.d. -g). The medium hub airports are Cincinnati/Northern Kentucky International Airport, Cleveland Hopkins International Airport, Pittsburgh International Airport, Portland International Airport, and St. Louis Lambert International Airport. The ASPM includes flights conducted by the ASPM carriers to domestic ASPM and non-ASPM airports, as well as airports worldwide.

Aviation System Performance Metrics generates the following six types of reports (FAA, n.d. -h): all flights report, delayed flights report, all flights comparison report, delayed flights comparison report, expect departure clearance time report, and expect departure clearance time compliance report. In this study, all flights report, all flights comparison report, delayed flights report, and delayed flights comparison reports were obtained from the ASPM. These reports provide data about flight operations and delays on multiple dates or at different airports.

Aviation System Performance Metrics also provides airport weather information, runway configurations, and rates of airport departures and arrivals (FAA, n.d. -i). The combination of airport information and flight data provides a robust picture for airports and air carriers about air traffic activities.

### 3.2.3 Interviews

To study the current perspective of airport operators regarding the risk of UAS, the researcher collected data through interviews with airport personnel. For the interviews, the researcher contacted five airport personnel by email, and all five airport personnel agreed to participate in the study. Interviews with the airport personnel were conducted in the summer of 2020 by phone calls.

#### 3.2.3.1 Approval of Interviews

To protect research participants, the interviews questions are required to be reviewed and approved by an Instructional Review Board (IRB). Most of the public institutes and all of the private agencies have their own IRB (Salkind, 2012, p. 90). The IRB of Purdue University is responsible for reviewing ethics in proposed research that involve human subjects (Purdue University, 2019). Except for research involving humans and being categorized as an exempted or waived study under 45 CFR § 46.102 (Protection of Human Subjects, 2009), all research conducted by Purdue University's faculty, students, staff, and affiliates and involves human subjects must be reviewed by the IRB of Purdue University, and approved prior to the initiation of research activities. In this study, interviews are required to be reviewed and approved by Purdue University IRB before the commencement of the study.

To get approval from Purdue University IRB, the researcher submitted an online application, including a recruitment email and interview questions, for the initial review on March 4, 2020. The IRB approval was received on March 9, 2020, which provided the permit to contact and conduct interviews for data collection. The IRB approval can be viewed in Appendix B.

In addition to receiving an IRB approval, this research study required approval from each participant from whom data were received. A recruiting email was sent to each participant specifying the purpose of this study, the rights of their participation, potential benefits, and contact information of the researcher. The recruiting email for the interview can be found in Appendix C.

#### 3.2.3.2 Interview Questions

The researcher designed 14 questions for the interview, including four categories of questions: UAS at the airport, comparison between UAS sightings and wildlife strikes, preventing and coping with UAS, and applications of UAS to airport operations. The interview questions were provided to interviewees a few days prior to the interview. Follow-up questions for clarification and additional detail are not included in the table but were asked when appropriate. The interview questions are shown in Table 3.1.

Table 3.1 Interview questions.

| Category | No. | Corresponding Interview Question |
|---|---|---|
| UAS at the airport | 1 | Have you had a UAS sighting at or in the vicinity of your airport? |
| | 2 | Has your airport deployed airport police or contacted local police regarding UAS in the vicinity of the airport in response to a UAS sighting? |
| | 3 | Has your airport recovered any drones on airport property? If yes, how many drones has your airport recovered (over what time period)? |
| Comparison between UAS sightings and wildlife strikes | 4 | Have you heard of the FAA's UAS Sightings Report datasets? |
| | 5 | Have you heard of the FAA's Wildlife Strike Database? |
| | 6 | Have you included UAS surveillance in your training, inspection, or safety bulletins or airport communications activities? |
| | 7 | Have you included wildlife surveillance in your training, inspection, or safety bulletins or airport communications activities? |
| Preventing and coping with UAS | 8 | Have you investigated drone detection technologies for your airport? |
| | 9 | Does your airport have a Tactical Response Plan for UAS sightings? |
| | 10 | How effective do you think your airport emergency plan (AEP) is for a drone sighting and or drone strike? |
| Comparison between UAS sightings and wildlife strikes | 11 | What is the overall threat due to UAS at your airport? |
| | 12 | What is the overall threat due to wildlife at your airport? |
| Applications of UAS to airport operations | 13 | Some airports have used UAS to support airport operations. Are you interested in using UAS for airfield inspections in the next year or two? |
| UAS at the airport | 14 | Would you like to share any other comments about your experience or thoughts regarding UAS and your airport? |

### 3.3 Data Analysis Strategy and Procedures

This section presents the data analysis used to address each of three components of this study. The study first investigated the UAS sighting reports published by the FAA using statistics to address the first research question. Subsequently, airport and flight operation data from the OPSNET and the ASPM were analyzed to answer the second research question. Finally, the interview results were studied which answered the third research question. Both qualitative and quantitative methods were utilized in this study.

### 3.3.1 UAS Sighting Reports

The FAA's UAS sighting reports were studied in both qualitative and quantitative ways. Firstly, UAS sighting reports were reviewed by the researcher to extra relevant information for this study. Thereafter, data extracted from UAS sighting reports were analyzed in quantitative ways.

#### 3.3.1.1 Qualitative Data Analysis

A qualitative data analysis methodology was adopted to review UAS sighting reports. The researcher selected 10 criteria, which reflect the characteristics of UAS sightings, and applied them to each UAS sighting reports to extract information from reports. This method had been used by Unmanned Aircraft Safety Team (UAST, 2017) to acquire and analyze the FAA's UAS sighting reports spanning August 2015 through March 2017. It provides reliable and potentially actionable insights to "enhance the veracity and informative nature of the reports" (UAST, 2017, p. 2). Table 3.2 shows the 10 selected criteria and the methodology for identification and analysis of the narrative in each UAS sighting report. The emphasis is on making sure that all entries contain consistent data, since the consistency in the data is important and necessary to conduct an analysis, to present results, and to draw conclusions.

Table 3.2 Methodology for qualitative analysis of UAS sighting reports.

| No. | Goal | Format | Methodology |
|---|---|---|---|
| 1 | To determine who reported the UAS sighting. | In text, “pilot,” “ATC,” “airport,” “passenger,” “citizen,” “law enforcement,” “military,” or “unknown.” | Exemplary statements: “U.S. PARK POLICE REPORTED SEEING A UAS,” “A PASSENGER SIGHTED A UAS,” and “C172 REPORTED A BLACK UAS.” |
| 2 | To determine the UAS altitude in feet. | Numeric with no special characters or “unknown.” | No assumptions were made. If the report stated, “drone passed above aircraft,” it was listed as unknown. |
| 3 | To determine the distance from the location of UAS to the airport in miles. | Numeric with no special characters or “unknown.” | No assumptions were made. If the report stated, “EASTBOUND OVER REDWOOD ROAD EAST OF SALT LAKE CITY ARPT,” it was listed as unknown. |
| 4 | To determine the airport that was close to the location of the UAS sighting. | In text, FAA’s airport code or “unknown.” | Narratives including specific airport that was close to the location of the UAS sighting. Exemplary statements: “2 NE SLC.” |
| 5 | To determine whether a MOR alert was issued. | In text, “yes” or “no.” | The MOR alert was shown in the narrative if the alert was issued. |
| 6 | To determine whether law enforcement department(s) was notified of the UAS sighting. | In text, “yes,” “no,” or “unknown.” | Narratives including specific departments that were notified of the UAS sighting were classified as “Yes.” Report that stated, “LEO NOTIFICATION NOT REPORTED,” was listed as “No.” An example of unknown: “LEO NOTIFICATION UNKN.” |
| 7 | To determine the type of manned aircraft involved in the UAS sighting. | In text, “commercial,” “GA,” “helicopter,” “military,” “no aircraft involved,” or “unknown.” | The type of manned aircraft involved in the UAS sighting was stated in the narrative. |
| 8 | To determine whether the pilot(s) took evasive action. | In text, “yes” or “no.” | Exemplary statements: “EVASIVE ACTION TAKEN,” “DESCEND TO AVOID,” and “BANKED LEFT.” |
| 9 | To determine how close the UAS was to the manned aircraft in feet. | Numeric with no special characters or “unknown.” | No assumptions were made. If the report stated, “OFF LEFT SIDE,” it is listed as unknown. |
| 10 | To determine the position from the manned aircraft to UAS. | In text, “above,” “below,” “left,” “right,” “front,” “behind,” or “unknown.” | Exemplary statements: “OBSERVED A BLACK UAS OFF HIS RIGHT SIDE,” and “DRONE PASSES IN FRONT OF THE AIRCRAFT.” |

#### 3.3.1.2 Quantitative Analysis

Quantitative analysis including descriptive and inferential statistical analysis were utilized to analyze UAS sighting reports. Descriptive statistics including mean, median, range, and standard deviation were used to show some of the characteristics of UAS sightings, including: the altitude of UAS, the distance from the location of the UAS sighting to the airport, and the distance between manned aircraft and UAS.

Inferential statistical method, especially regression analysis methods, are frequently used in transportation research (e.g. Hubbard, et al., 2009; Zhan, et al., 2009). In this study, the researcher used the binary logistic regression method to study relationships between independent variables and the dependent variable (Washington et al., 2003). By applying the binary logistic regression model, relationships between the characteristics of UAS sightings and the possibility of a UAS sighting requiring evasive actions were analyzed. The general form of probability in a logistic model is as follows:

$$P\,(y_i = 1) = p_i = e^{\alpha+\beta x_i} / (1 + e^{\alpha+\beta x_i})$$

where $y$ is a binary dependent variable, $y_i = 1$ if the trait is present in observation $i$, $y_i = 0$ if the trait is not present in observation $i$; $x$ is a set of independent variables which can be discrete, continuous, or a combination, and $x_i$ is the observed value of the independent variables for observation $i$; $p_i$ is the probability that an observation $i$ will occur; $\alpha$ is the constant; $\beta$ is the vector of coefficients for independent variables. The significance level was set at the level of 0.05, which is commonly accepted in academia (Parasuraman et al., 2007).

A valid binary logistic regression model must meet certain assumptions. These assumptions include (Kassambara, 2018; Wright, 1995):

- The sample size is sufficiently large,
- Dependent variables are independently distributed,
- Categories of the dependent variable are mutually exclusive and collectively exhaustive,
- The model contains all and only relevant independent variables,
- There is no outliners or extreme values in continuous independent variables, and
- There is a linear relationship between the logit of the dependent variable and each independent variable.

### 3.3.2 Case Study

A case study describes an event in-depth and was used to investigate the impact of the UAS sighting at EWR on January 22, 2019. To understand the impact of the UAS sighting on airport operations, the following data were obtained from the FAA's OPSNET and ASPM data and analyzed by using paired sample t-tests, which determine whether differences in observed data were statistically significant.

- Gate departure and gate arrival delays by date and airport.
- Taxi out and taxi in delays by date and airport.
- Average taxi out time by date and airport.
- Airport departure delays, airborne delays, and block delays by date and airport.
- Percent of on-time gate departures and gate arrivals by date and airport.
- Average minutes of delay per delayed gate departure/arrival by date and airport.
- Percent of delayed gate departures by date and airport.
- Percent of on-time airport departures by date and airport.

In addition, aircraft operations, number and percent of delays, and average length of delays by date, airport, class, and cause were also analyzed.

### 3.3.3 Interviews

The interview data was analyzed using the steps proposed by Galletta (2013, pp. 119-45) for semi-structured interview data. Upon completion of an interview, the researcher completed a post interview reflection by noting core ideas collected from the interview. Then, the researcher organized and coded the information collected from the interviews. The researcher identified six areas: UAS sighting, database, training and communication, airport threat, wildlife strike, UAS detection and management, and application of UAS.

## 3.4 Validity of Research

Validity is an important concept in research. Joppe (2000) defined validity as a determination "whether the research truly measures that which it was intended to measure or how truthful the research results are" (p. 1). Research validity is affected by all phases of research, which include research design, data collection, and data analysis. Ensuring validity is important and necessary in all research, although it can be challenging. The following sections discuss the potential threats to validity and strategies which are used to ensure the validity of this study.

### 3.4.1 Potential Threats to Research Validity

There were two issues that posed potential threats to the validity of this study. First, this study was limited by the means of data collection, namely use of the UAS sighting reports collected by external parties. UAS sighting reports that were used in this study were reported by the public, collected by the FAA Flight Standards District Offices (FSDO), and stored in the FAA's UAS sighting database. Therefore, the truthfulness and accuracy of the data and completeness of the reports were limited to the information reported.

The limited number of interviews was another challenge for this research. The interview was one of the primary data collection methods of this dissertation. However, due to limitations of time and resources, it was unrealistic to conduct large-scale interviews and collect data from all of the airports in the U.S. In addition, each airport varies in terms of the size, location, ownership, and service provided. The understanding of the current perspective of airport operators on UAS was based on a limited number of interviews. It is likely that different airports may have different perspectives on UAS. Accordingly, it is necessary to incorporate effective strategies into the interview design of this study to ensure research validity.

### 3.4.2 Strategies for Ensuring Research Validity

Two strategies were used in this study to ensure research validity. Firstly, the researcher used external audits to ensure the validity of the research design and findings. An external audit involves "having a researcher not involved in the research process examines both the process and product of the research study. The purpose is to evaluate the accuracy and evaluate whether the findings, interpretations, and conclusions are supported by the data" (Cohen & Crabtree, 2008, p. 334). For this study, the researcher asked aviation researchers who were not related to this study to examine the research design and research findings.

Another strategy that was used by the researcher was thick description. According to Polit and Becket (2010), thick description is "rich, thorough descriptive information about the research setting, study participants, and observed transactions and processes" (p. 1453). Descriptive information plays an essential role in assisting readers in deciding if findings from another study can be transferred to their own research. To improve the transferability of this study, a high quality of thick description of research contents, research settings, and information of airport and interviewees was provided by the researcher. According to the detailed information, readers are able to decide whether he/she can transfer the findings from this dissertation.

## 3.5 Summary

This chapter introduced the design of this study and the mixed-method methodology applied to this study. Data sources, data collections, as well as data analysis strategies and procedures were explained in detail. Finally, this chapter presented potential threats to the validity of the study and strategies for ensuring research validity.

# CHAPTER 4. RESULTS

This chapter presents research results including the characteristics of 6,551 UAS sightings reported between September 2016 and August 2019, and a binary logistic regression model that is applied to analyze the relationships between the characteristics of UAS sightings and the possibility of a UAS sighting that requires evasive action. Thereafter, a case study on the EWR UAS sighting is discussed. Finally, this chapter presents the results of five interviews conducted with four airport managers and an airport operations supervisor.

## 4.1 UAS Sighting Reports

Between January 1$^{st}$, 2015, and December 31$^{st}$, 2019, a total of 9,552 UAS sightings were recorded in the FAA UAS Sightings Reports dataset. According to the FAA, the number of UAS sightings increased substantially between 2015 and 2018. Figure 4.1 shows the number of UAS sighting reports by year.

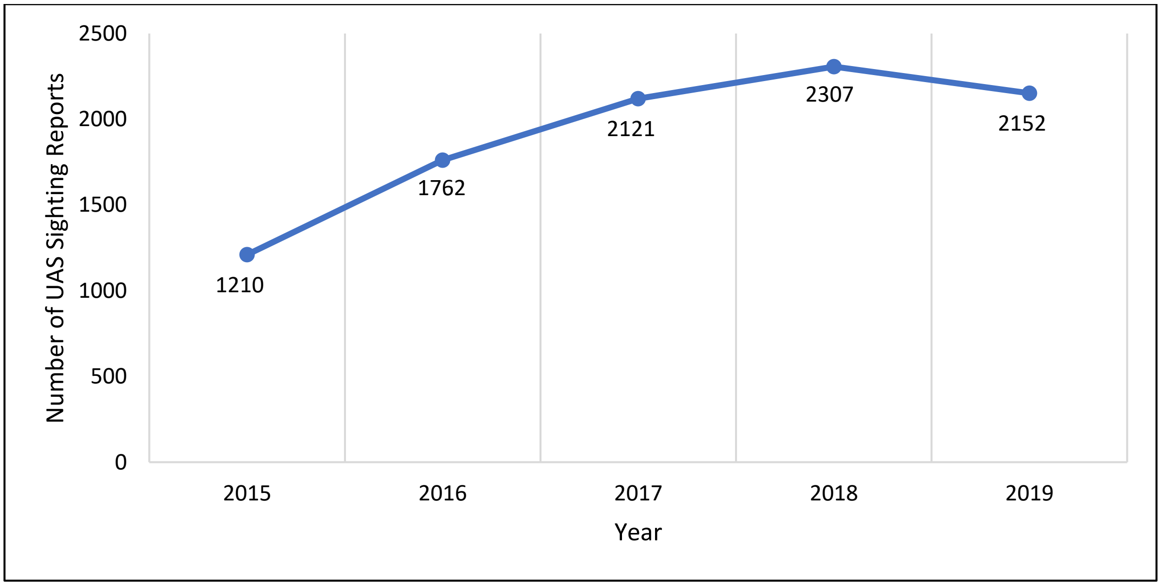
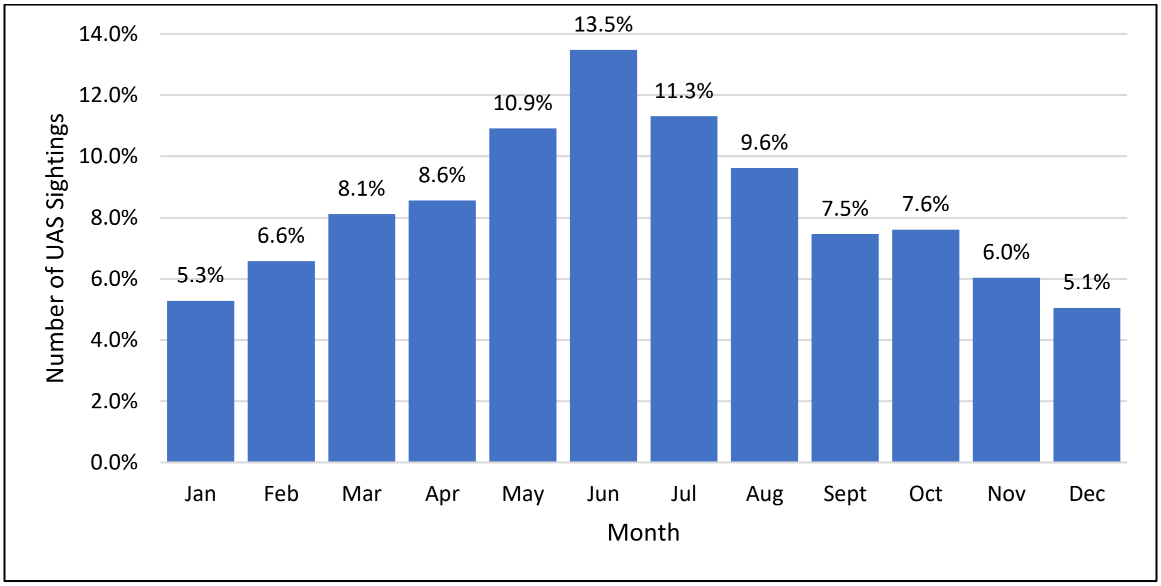



Figure 4.1 UAS sighting distribution by year.

### 4.1.1 Descriptive Statistical Analysis of UAS Sighting Reports

UAS sightings reported between September 2016 and August 2019 were analyzed by the researcher, including 534 reports from 2016, 2,121 reports from 2017, 2,303 reports from 2018, and 1,586 reports from 2019. Seven reports were excluded from the 6,551 UAS sighting reports, because they involved something other than a UAS (e.g., balloons and birds).

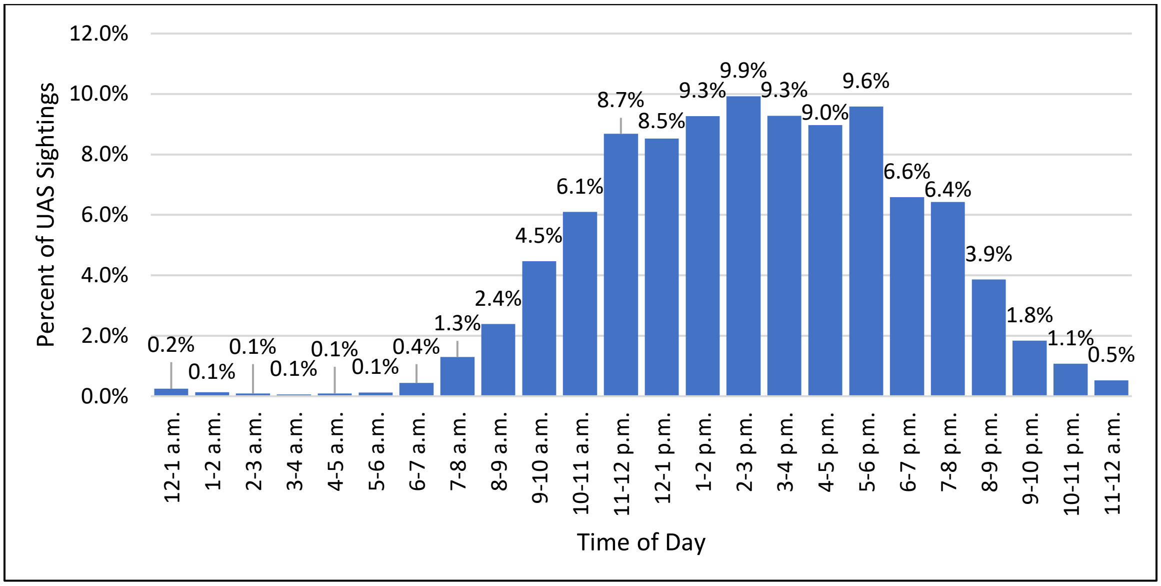
UAS sightings generally vary by time of year and time of day. Figure 4.2 shows the distribution of UAS sightings by month and by time of day. The most UAS sightings were reported in June, they tapered off in the fall, and were lowest in the winter; UAS sightings began to increase again in the spring. The top three months for UAS sighting reports were June, July, and May and 45.3 percent of all UAS sightings occurred between May and August. This distribution was likely due to increased UAS flights in the summer months, as well as increased GA traffic in the summer months (Mathew et al., 2017). The majority of UAS sightings occurred during the daytime, with 76.9 percent between 11 a.m. and 6 p.m. local time. This is consistent with 14 CFR Part 107 regulations which do not allow UAS operations from dusk to dawn (although FAA does grant waivers). This also reflects trends in both GA and commercial flights; most commercial flights are between 7 a.m. and midnight; recreational GA flights are most common during daylight hours.




(a) By month

Figure 4.2 UAS sighting distribution (Sep. 2016 to Aug. 2019).

Figure 4.2 continued




(b) By time of day

The timing of manned flights was relevant for UAS sightings, since 93.5 percent of UAS sighting reports were made by pilots, as shown in Figure 4.3. This is not surprising, because pilots are accustomed to working with the FSDO, the organization that is the conduit for the reports in the UAS Sightings database. Pilots are also directly affected by unsafe UAS operations and most likely to see UAS, since they are in the air and actively observe surroundings out of the cockpit window. Concerned citizens, airport officers, LEOs, passengers, air traffic controllers and others also reported UAS sightings, but collectively represented only 6.5 percent of the reports submitted. Although there are over 14,000 air traffic controllers in the U.S., which is three percent of the number of pilots in the U.S., less than one percent of UAS sightings were reported by air traffic controllers (FAA, 2020e, 2020f). Anecdotal evidence based on conversations with airport managers and airport operations personnel (discussed further in section 4.3) suggests that there is a general lack of awareness about the FAA UAS Sightings database in the airport community, including both the existence of the database and how to submit a UAS sighting report.

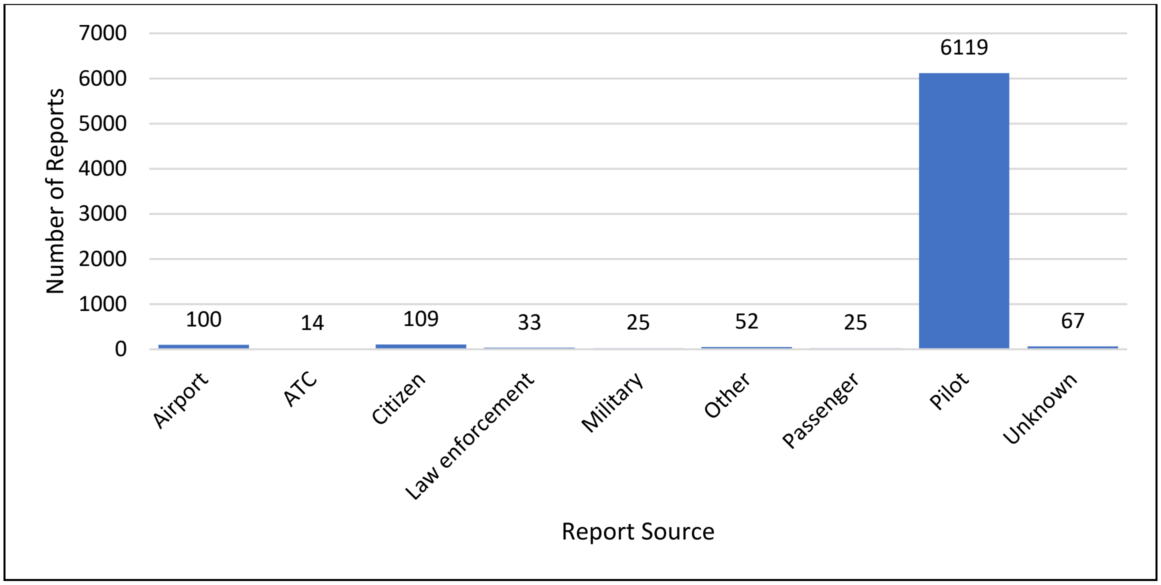
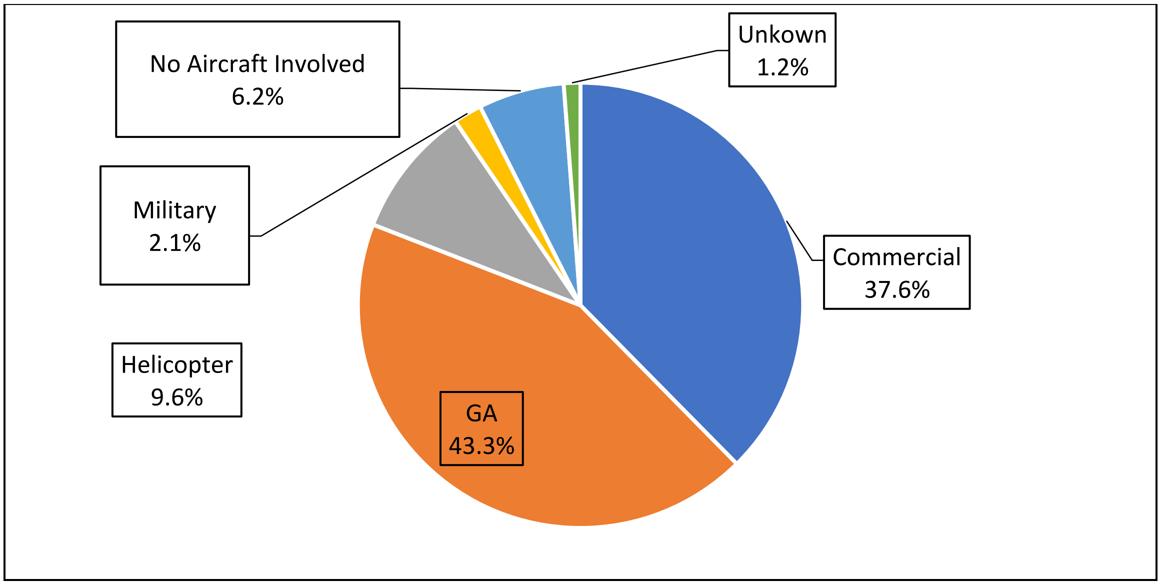
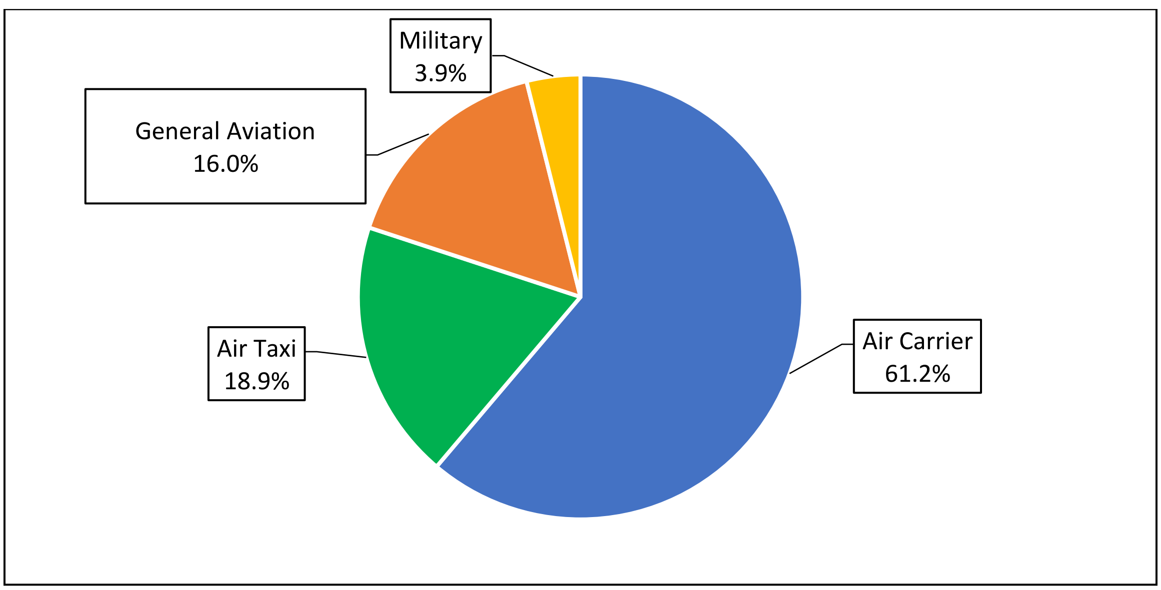



Figure 4.3 UAS sighting reports by report source (representing all 6,544 UAS sightings from Sept. 2016 to Aug. 2019).

All kinds of aircraft are at risk from UAS, and this is reflected by the fact that pilots from a wide variety of aircraft filed UAS sighting reports. Pilots of GA aircraft (such as a Cessna 172) and business jets (such as a Hawker 400) reported the most UAS sightings, representing 43.3 percent of the reports, as shown in Figure 4.4(a). Pilots of large commercial aircraft (such as A320 and CRJ 700) also reported UAS sightings, and account for 37.6 percent of the UAS sightings. This suggests that both GA and commercial flight operations are vulnerable to UAS sightings, which may result in flight delays, diversions, cancelations, closure of runways, or even airport closure.




(a) UAS sightings (representing all 6,544 UAS sightings from Sep. 2016 to Aug. 2019)




(b) Airport operations (Sep. 2016 to Aug. 2019)

Figure 4.4 Types of aircraft operations.

The high number of UAS sighting reports by GA aircraft is more striking when the operational mix is considered. General aviation account for only 16.0 percent of operations as shown in Figure 4.4(b) (FAA, n.d. -j), but comprised 43.3 percent of UAS sightings. This may be due to the lower altitudes of GA flights and may suggest that GA are more vulnerable to UAS, and thus may warrant additional outreach effects. In contrast, commercial operations account for 61.2 percent of all operations, although only 37.6 percent of UAS sightings involved commercial aircraft. This may be due to the fact that most of the commercial flights fly above the altitude of UAS, and certainly above the altitude of UAS operating under Part 107, which mandates a maximum height of 400 feet.

In some cases, it is appropriate to report the UAS sighting to local law enforcement for investigation. Figure 4.5 shows that in 73.8 percent of UAS sightings, law enforcement (e.g., airport police, local police, county sheriff, or state police) was notified or follow up actions were taken by relevant departments. In a quarter of UAS sighting reports, it was not known if there was any report to local law enforcement (15.8 percent of the reports), or the UAS sighting was not reported to local law enforcement (10.4 percent of the reports). Although law enforcement agencies were notified the majority of the time, it is difficult to enforce UAS regulations and not all law enforcement has the resources or capabilities to deal with UAS sightings. Often the operator of the UAS could not be found, which makes enforcement of unauthorized or illegal operations impossible.

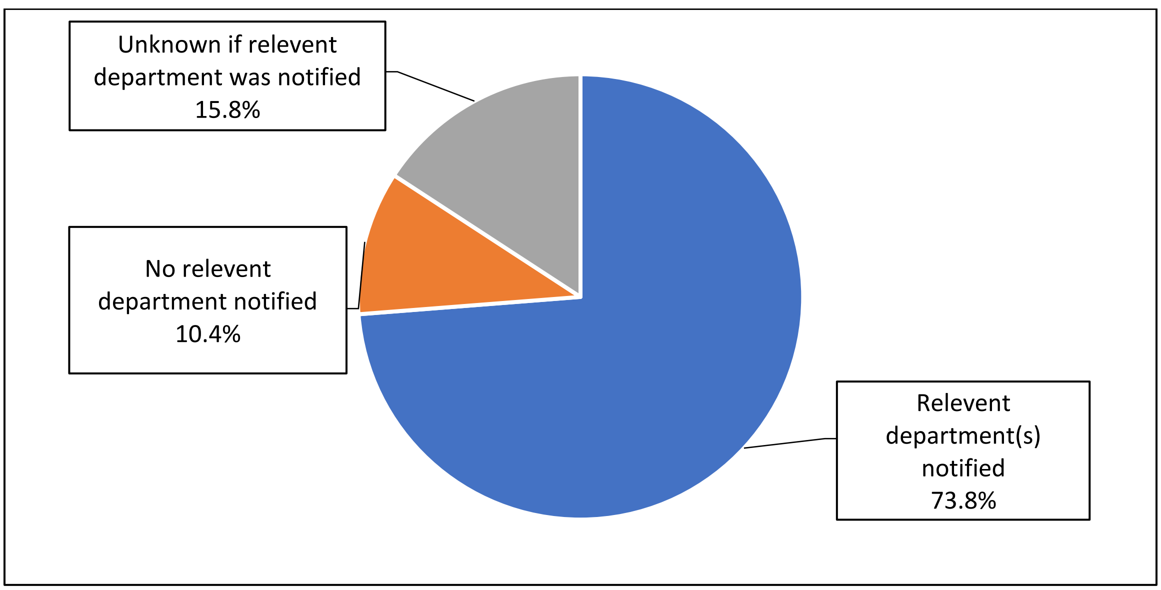



Figure 4.5 UAS sighting reports by law enforcement notification (representing all 6,544 UAS sightings from Sep. 2016 to Aug. 2019).

UAS sightings may also be reported within FAA's ATC reporting system through a MOR. A MOR alert can be reported by air traffic controllers, aircraft operators, aircraft owners, front line managers, or other parties. A MOR is mandatory for an occurrence that involves air traffic services (FAA, 2012). It is reported when one of the following situations appears:

- Suspected airborne or surface loss,
- Improper or unexpected operation of aircraft near terrain or obstruction,
- Aircraft communication issues, or
- In-flight emergency conditions (such as a UAS sighting or a bird strike).

Mandatory occurrence report alerts were issued for 86.2 percent of the UAS sightings. As shown in Figure 4.6, a MOR alert was issued over 90 percent of the time when the UAS sighting was reported by ATC or a passenger, 87 percent of the time when the UAS was sighted by a pilot, over 70 percent of the time when the UAS was sighted by an airport operation personnel or a citizen, and 40 percent of the time when the UAS was reported by the military. The UAS sighting database plays an important role in capturing the UAS sighting data, because about 15 percent of the reports in the UAS sighting database were not reported to the MOR reporting system.

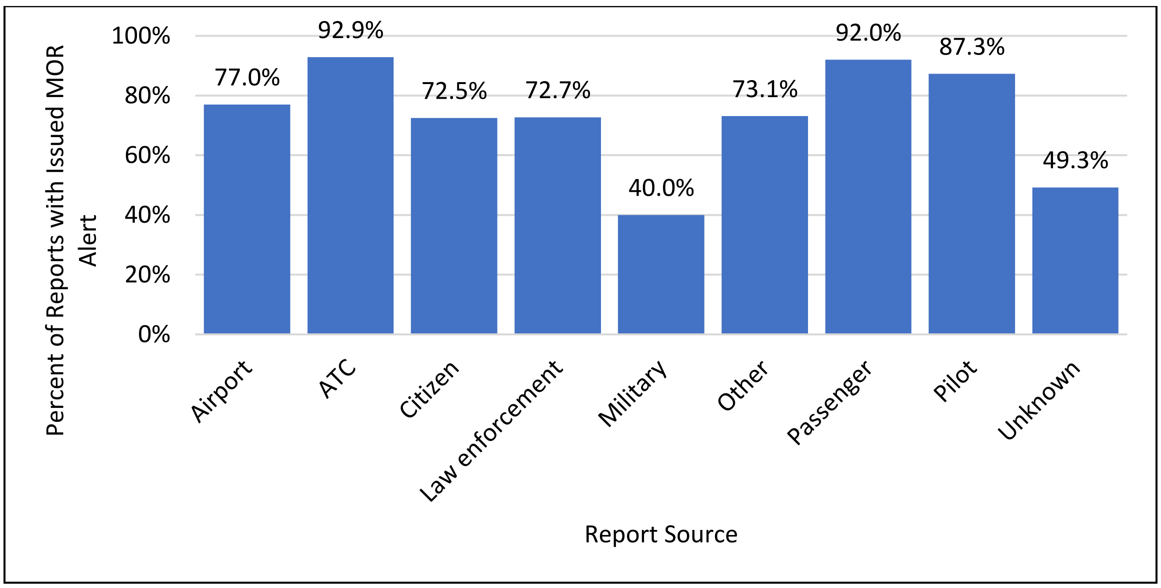



Figure 4.6 Percentage of UAS sighting reports with issued MOR alert by report source (representing all 6,544 UAS sightings from Sep. 2016 to Aug. 2019).

Given the safety risk of UAS, pilots also reported the position of UAS relative to manned aircraft. Figure 4.7 shows the reported position of UAS sightings. Fifty-eight percent of UAS sighting reports included position; most reports indicated that the UAS was below the aircraft (39.7 percent), the least reported position of the UAS was behind the aircraft (0.7 percent), and UAS were equally likely to be reported to either side (20.4 percent on the left and 20.7 percent on the right). The data may reflect both visibility and where the pilot tends to look while flying, in addition to the relative position of the UAS. Five percent of UAS were in front of the aircraft, which is generally consistent with the reported finding that only 3.3 percent of UAS sightings required the pilot to take evasive action.

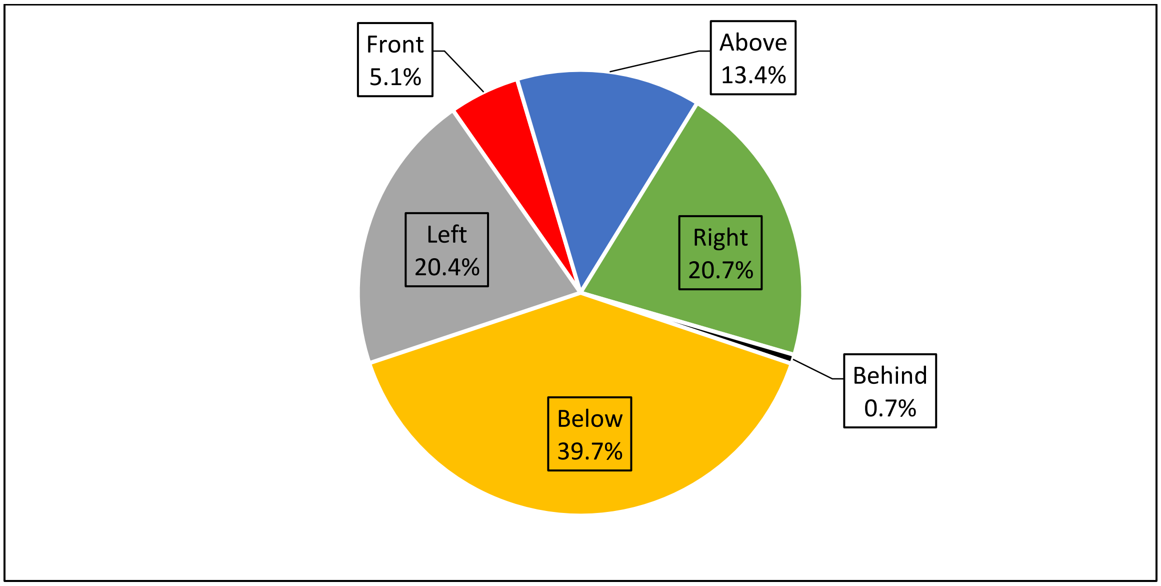
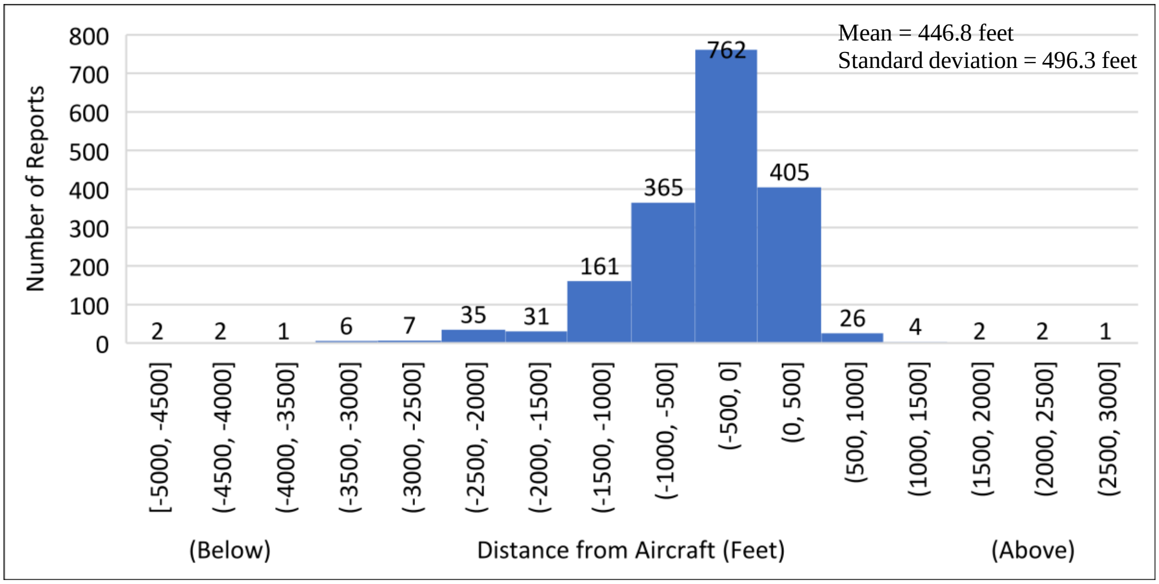
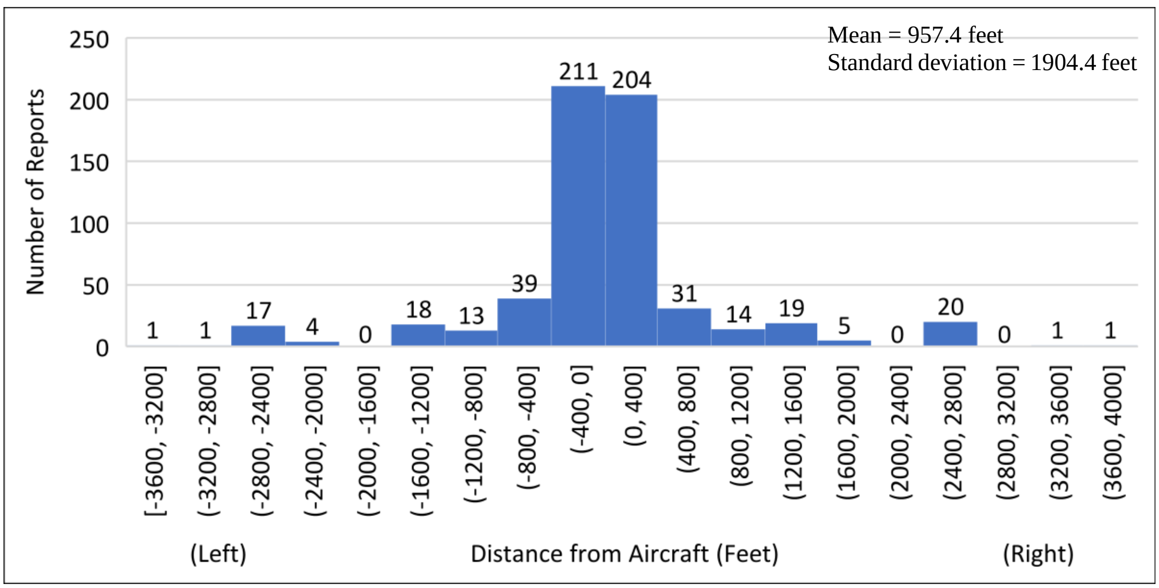



Figure 4.7 Position of UAS relative to aircraft (Sep. 2016 to Aug. 2019).

Close encounters between manned aircraft and UAS are a serious safety concern. About half of the UAS sighting reports included the distance between the manned aircraft and the UAS. As shown in Figure 4.8(a), pilots were more likely to report UAS that were close to their aircraft, presumably because they present a greater hazard. For the UAS sightings in which the distance between the UAS and the manned aircraft was recorded (78 percent of all UAS sightings), 90 percent were within 1,000 feet of the aircraft, and 78 percent indicated that the UAS was within 500 feet of the aircraft. Considering a commercial jet at a takeoff speed of 150 miles per hour (equals to 220 feet per second) (Scott, 2002), the pilot has less than five seconds to take evasive action when the UAS was within 1,000 feet in front of the aircraft. For a GA aircraft, the pilot has less than nine seconds to avoid a collision at a takeoff speed of 80 miles per hour (117.3 feet per second) of a UAS sighting within 1,000 feet of the aircraft (Lafayette Aviation, n.d.).



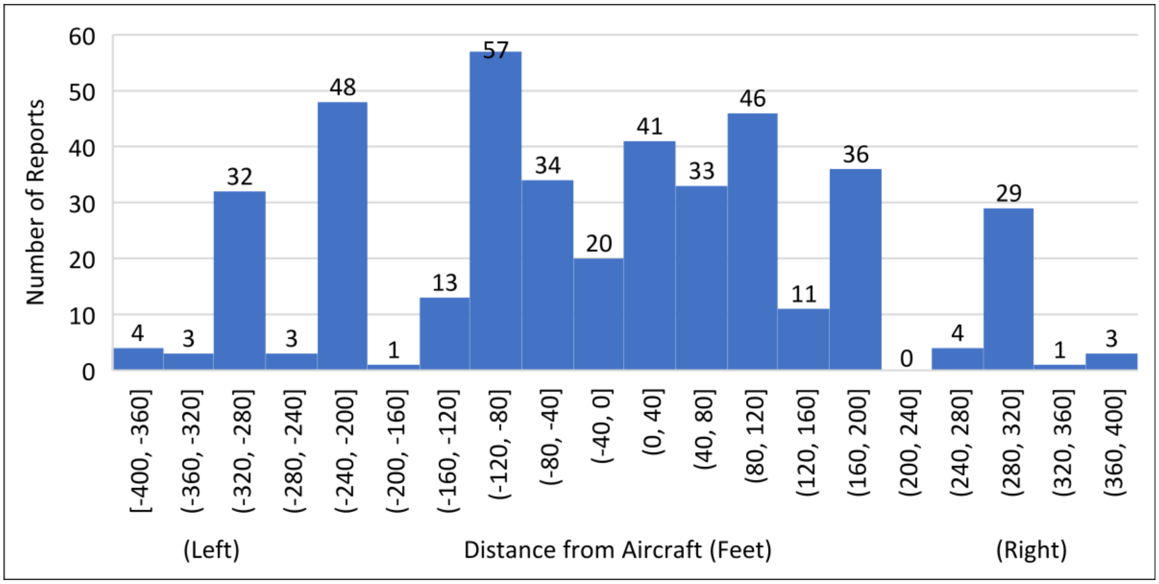

(a) Vertical distance between UAS and aircraft (above or below aircraft).




(b) Horizontal distance between UAS and aircraft within 4,000 feet (right or left of aircraft).

Figure 4.8 Proximity of UAS to aircraft (Sep. 2016 to Aug. 2019).

Figure 4.8 continued




(c) Horizontal distance between UAS and aircraft within 400 feet (right or left of aircraft).

The median distance of the UAS relative to an aircraft was 200 feet, which is much less than the average horizontal distance of 1,000 feet between the UAS and the aircraft. UAS as far away as three miles (15,800 feet) had been reported, although it is presumably harder to accurately estimate the distance of UAS that are farther away, and the reported UAS sightings at long distances skew the value of the average distance. Figure 4.8(b) shows proximity to aircraft, for UAS within 4,000 feet of the aircraft; this includes 93 percent of all UAS sightings. As it shown in Figure 4.8(b), the number of UAS sightings are symmetrically distributed and centered at zero, 79 percent of the reported UAS were within 1,000 feet of the aircraft, and 85 percent were within 2,000 feet of the aircraft. As more than half of the UAS sightings were reported within 400 feet of the aircraft, Figure 4.8(c) further shows proximity to aircraft, for the 65 percent of UAS sightings within 400 feet of the aircraft. UAS sightings were most frequently reported when the UAS was less than 120 feet from the aircraft.

Airport operators are interested in any UAS that are in the proximity of the airport and can potentially affect airport operations and the safety of planes landing and taking off. Figure 4.9 shows UAS sightings by altitude and distance from the airport. Orange markers stands for UAS sightings occurred within five miles of an airport and below 2,500 feet; blue markers are UAS sightings occurred out of the range. Generally, UAS sightings beyond 10 miles of an airport occurred at higher altitudes than UAS sightings within 10 miles of an airport, which is reasonable since aircraft tend to be at higher altitudes when they are farther from an airport. The average altitude of UAS sightings with a recorded airport distance of more than 10 miles was 6,076 feet, which is within the altitude range of flights under VFRs and may pose risk to GA aircraft during the cruise phase; the average altitude of UAS sightings within 10 miles of an airport was 2,692 feet, which is higher than the usual traffic pattern altitude at 1,000 feet above ground level and may be threat to climbing or descending aircraft. In some cases, pilots reporting UAS sightings may reported their location relative to their origin or destination airport, rather than the nearest NPIAS airport.

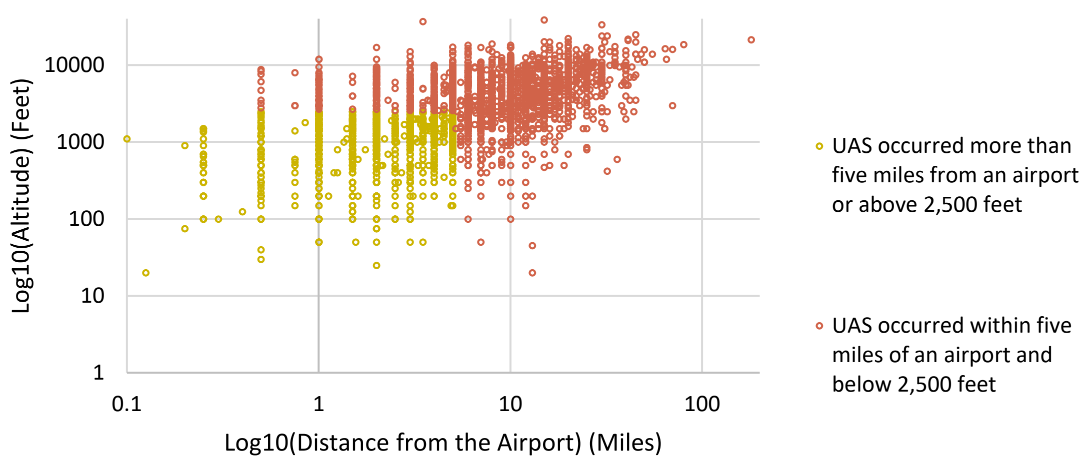
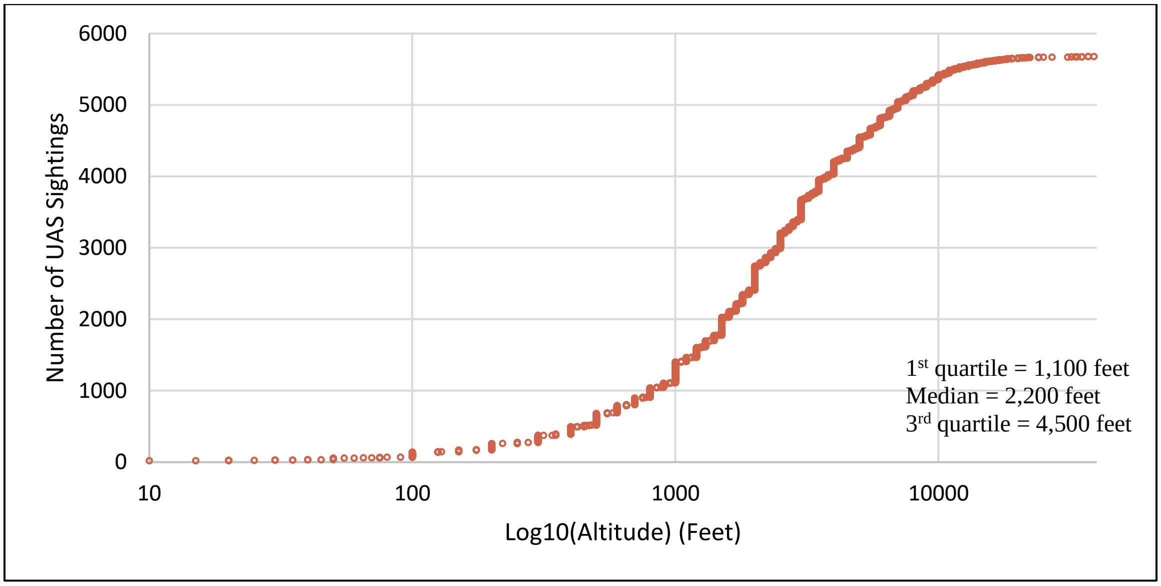



Figure 4.9 UAS sightings by altitude and distance from the airport (Sep. 2016 to Aug. 2019).

According to the FAA (2006), TRACON controllers hand aircraft off to air traffic controllers in the airport control tower when an aircraft that is landing is within five miles of an airport and below 2,500 feet. Hence, airport traffic control towers and airport operations should be responsible for UAS sightings within this range, which are shown in orange in Figure 4.9. Since TRACON controllers guide aircraft departing and approaching airports generally within a 30- to 50-mile radius up to 10,000 feet, and aircraft that fly over that airspace, UAS that occur between 30 and 50 miles from an airport and below 10,000 feet should be handled by TRACON controllers. When UAS sightings are reported more than 50 miles from the airport or above 10,000 feet, it is air route traffic controllers' responsibility to manage the UAS sighting.

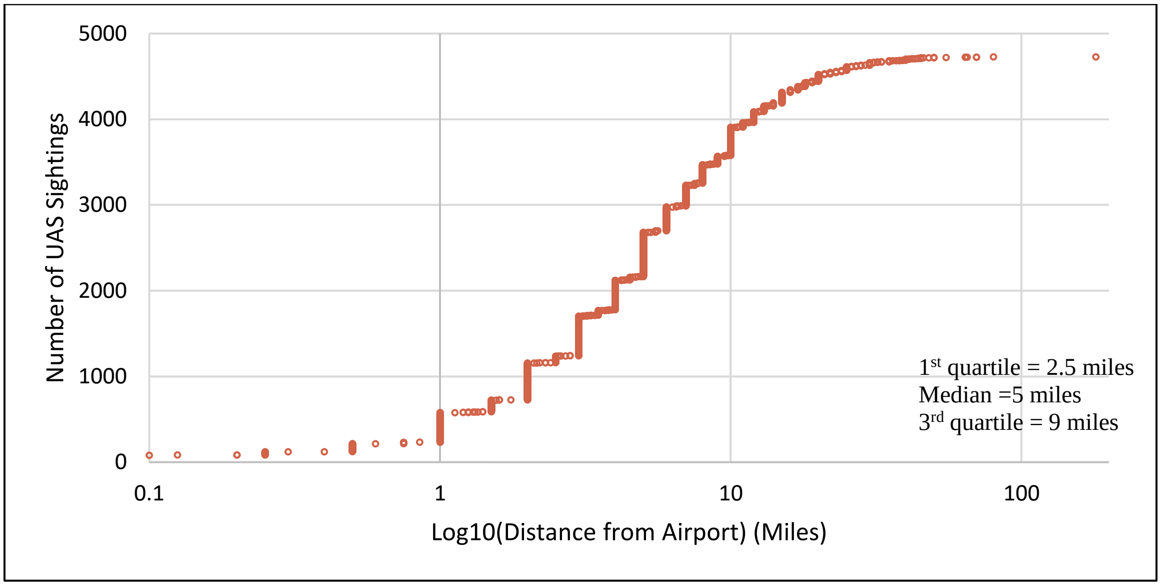
In terms of altitude, most UAS sightings occurred above the maximum altitude of 400 feet per Part 107 regulations. Of the UAS sighting reports that included an altitude (87 percent of all UAS sightings), only nine percent of UAS were operated at or below 400 feet, and 91 percent occurred above 400 feet; these results reflect a lack of compliance with Part 107. In this study, the highest recorded altitude for a UAS was 39,000 feet, 1,645 UAS sightings occurred above 4,000 feet, and most UAS sightings (3, 539) occurred between 400 feet and 4,000 feet. The average altitude for UAS sightings was 3,355 feet, and the median altitude was 2200 feet. Figure 4.10(a) shows the cumulative distribution of UAS sightings by altitude, which suggests that most of the reported UAS operated between 1,000 and 10,000 feet, which is surprising since most consumer UAS are not designed for altitudes above 1,000 feet; not surprisingly, there are few UAS reported above 10,000 feet due to the capability of UAS.




(a) By altitude (excluding UAS sightings that reported the altitude was zero)

Figure 4.10 Cumulative distribution of UAS sightings (Sep. 2016 to Aug. 2019).

Figure 4.10 continued




(b) By distance from the airport (excluding 84 UAS sightings that reported the distance was zero)

The FAA not only restricts the altitude of UAS operations but also prohibits the operation of UAS in controlled airspace unless permission is obtained from ATC. UAS operators may able to access to controlled airspace at or below 400 feet with the support from the FAA UAS data exchange approach, commonly called Low Altitude Authorization and Notification Capability, which is a fast and convenient way for UAS operators to obtain permission to fly in controlled airspace (FAA, 2020g). For the UAS sightings in which the distance from an airport was recorded (72 percent of all UAS sightings), 57 percent occurred within five miles of the reported airport; 83 percent occurred within 10 miles of the reported airport; and 99 percent occurred within 30 miles of the airport. The average distance from an airport was 6.94 miles, and the median was five miles. It is notable that a few UAS sightings occurred up to 180 miles from the reported airport. These UAS sightings that were reported more than 50 miles from an airport may reflect the nearest commercial airport, or the airport where the aircraft took off or plans to land. Figure 4.10(b) shows the cumulative distribution of UAS sightings by distance from the airport, indicating that most of the UAS sightings occurred less than 10 miles from the reported airport.

The need for evasive action by a pilot of a manned aircraft to avoid a UAS implies a near miss. It is affected by the distance and relative speed between an aircraft and a UAS, and whether there is time to take evasive action, which is affected by the relative location, speed, and maneuverability of the aircraft. Fortunately, aircraft rarely had to take evasive action to avoid a UAS, as shown in Table 4.1, which provides information about pilot evasive maneuvers by aircraft type. Table 4.1 shows that pilots only took evasive actions in only 3.3 percent of the cases, and no evasive action was taken in 96.7 percent of cases. General aviation aircraft and helicopters were more likely to take evasive actions than commercial aircraft, which may be due to the altitudes at which they commonly fly, the lower speeds at which they travel, their ability to change course more quickly, and their vulnerability to damage if there is a collision with a UAS. Overall, GA aircraft are at greater risk regarding UAS sightings relative to commercial aircraft.

Table 4.1 UAS sighting reports by aircraft type and evasive action (Sep. 2016 to Aug. 2019).

| **Percent (Number)** | **Total** | **GA Aircraft** | **Commercial Aircraft** | **Helicopter** | **Military Aircraft** | **Aircraft Type Unknown** |
|---|---|---|---|---|---|---|
| UAS sightings did not require evasive action | 96.7% (5,925) | 45.7% (2,706) | 41.3% (2,445) | 9.6% (567) | 2.2% (128) | 1.3% (80) |
| UAS sightings that required evasive action | 3.3% (210) | 60.5% (127) | 7.6% (16) | 28.6% (60) | 3.3% (7) | 0.0% (0) |
| Total UAS sightings | 100.0% (6,135) | 46.2% (2,833) | 37.6% (2,461) | 10.2% (627) | 2.2% (135) | 1.3% (80) |

These results are consistent with the Heinrich's Law (1941), which states that "for every accident that causes a major injury, there are 29 accidents that cause minor injuries and 300 accidents that cause no injuries." The consistency between the ratio of evasive action in reported UAS sightings and the Heinrich's Law indicates that there were 63,000 UAS sightings that were not reported to the FAA's UAS sighting database. Figure 4.11 illustrates the Heinrich's Law and its application to UAS sightings.

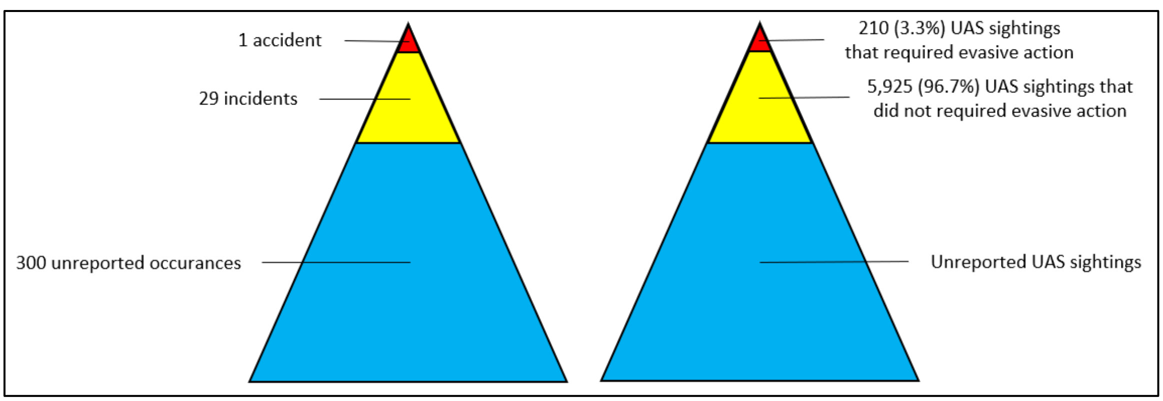



Figure 4.11 The Heinrich Law (left) and its application to UAS sightings (right).

Not only the percent of pilot evasive maneuvers varied in aircraft type but also the frequency of UAS sightings varies signficicantly, depending on the state and airport category. States that have large populations and cities with higher population densities had more UAS sightings. Table 4.2 provides a breakdown of reports, population, NPIAS airports, and primary airports by state (United States Census Bureau, 2019; FAA, 2018a).

Table 4.2 UAS sighting reports by state (Top 30, including Washington D.C., Sept. 2016 to Aug. 2019).

| Rank | State | Number (%) of Reports | Population in Thousand (%) | Number (%) of NPIAS Airports | Number (%) of Primary Airports | Average Number of Reports per Primary Airport |
|---|---|---|---|---|---|---|
| 1 | California | 1,097 (16.9%) | 39,512 (12.0%) | 190 (5.8%) | 22 (6.0%) | 49.9 |
| 2 | Florida | 777 (12.0%) | 21,478 (6.5%) | 100 (3.0%) | 20 (5.5%) | 38.9 |
| 3 | New York | 638 (9.8%) | 19,454 (5.9%) | 83 (2.5%) | 16 (4.4%) | 39.9 |
| 4 | Texas | 560 (8.6%) | 28,996 (8.8%) | 210 (6.4%) | 24 (6.6%) | 23.3 |
| 5 | New Jersey | 237 (3.7%) | 8,882 (2.7%) | 24 (0.7%) | 3 (0.8%) | 79.0 |
| 6 | Illinois | 228 (3.5%) | 12,672 (3.9%) | 85 (2.6%) | 10 (2.7%) | 22.8 |
| 7 | Arizona | 227 (3.5%) | 7,279 (2.2%) | 59 (1.8%) | 9 (2.5%) | 25.2 |
| 8 | Georgia | 191 (2.9%) | 10,617 (3.2%) | 97 (2.9%) | 7 (1.9%) | 27.3 |
| 9 | Washington | 178 (2.7%) | 7,615 (2.3%) | 64 (1.9%) | 10 (2.7%) | 17.8 |
| 10 | Pennsylvania | 173 (2.7%) | 12,802 (3.9%) | 63 (1.9%) | 9 (2.5%) | 19.2 |
| 11 | North Carolina | 163 (2.5%) | 10,488 (3.2%) | 72 (2.2%) | 10 (2.7%) | 16.3 |
| 12 | Massachusetts | 149 (2.3%) | 6,893 (2.1%) | 28 (0.8%) | 6 (1.6%) | 24.8 |
| 13 | Colorado | 139 (2.1%) | 5,759 (1.8%) | 49 (1.5%) | 9 (2.5%) | 15.4 |
| 14 | Nevada | 129 (2.0%) | 3,080 (0.9%) | 30 (0.9%) | 5 (1.4%) | 25.8 |
| 15 | Virginia | 124 (1.9%) | 8,536 (2.6%) | 47 (1.4%) | 8 (2.2%) | 15.5 |
| 16 | Michigan | 112 (1.7%) | 9,987 (3.0%) | 95 (2.9%) | 15 (4.1%) | 7.5 |
| 17 | Washington D.C. | 102 (1.6%) | 706 (0.2%) | 1 (0.0%) | 0 (0.0%) | 0.0 |
| 18 | Tennessee | 89 (1.4%) | 6,829 (2.1%) | 69 (2.1%) | 5 (1.4%) | 17.8 |
| 19 | Ohio | 86 (1.3%) | 11,689 (3.6%) | 99 (3.0%) | 7 (1.9%) | 12.3 |
| 20 | Oregon | 75 (1.2%) | 4,218 (1.3%) | 57 (1.7%) | 5 (1.4%) | 15.0 |
| 21 | South Carolina | 72 (1.1%) | 5,149 (1.6%) | 53 (1.6%) | 6 (1.6%) | 12.0 |
| 22 | Maryland | 68 (1.0%) | 6,046 (1.8%) | 18 (0.5%) | 3 (0.8%) | 22.7 |
| 23 | Utah | 68 (1.0%) | 3,206 (1.0%) | 36 (1.1%) | 5 (1.4%) | 13.6 |
| 24 | Minnesota | 66 (1.0%) | 5,640 (1.7%) | 97 (2.9%) | 8 (2.2%) | 8.3 |
| 25 | Louisiana | 61 (0.9%) | 4,649 (1.4%) | 56 (1.7%) | 7 (1.9%) | 8.7 |
| 26 | Connecticut | 59 (0.9%) | 3,565 (1.1%) | 13 (0.4%) | 2 (0.5%) | 29.5 |
| 27 | Alabama | 57 (0.9%) | 4,903 (1.5%) | 74 (2.2%) | 5 (1.4%) | 11.4 |
| 28 | Kentucky | 55 (0.8%) | 4,468 (1.4%) | 55 (1.7%) | 5 (1.4%) | 11.0 |
| 29 | Missouri | 53 (0.8%) | 6,137 (1.9%) | 75 (2.3%) | 5 (1.4%) | 10.6 |
| 30 | Hawaii | 51 (0.8%) | 1,416 (0.4%) | 15 (0.5%) | 7 (1.9%) | 7.3 |

As shown in Table 4, the four states with the most UAS sightings were California, Florida, New York, and Texas; these states also have the largest populations; UAS sightings from the top ten states accounted for two-third of UAS sighting reports and about half of the U.S. population.

The states with the most NPIAS airports are Alaska, Texas, California, and Florida; except for Alaska, the other three states also had the most UAS sightings. The states with the most primary airports are California, Florida, New York, and Texas; these four states are also the top four states in terms of UAS sightings. In addition, as the 5$^{th}$ ranked, New Jersey had a lot of UAS sightings relative to the population, the percent of NPIAS airports, and the percent of primary airports. Half of the UAS sightings in New Jersey occurred close to EWR, which is located in the New York metropolitan area and is the 5$^{th}$ ranked airport in terms of the number of UAS sightings. Hence it is not surprised that EWR had the first and the only UAS sighting that occurred at a major airport in the U.S. (discussed further in section 4.2).

Between September 2016 and August 2019, a total of 856 airports had UAS sightings, including 270 primary airports and 586 non-primary airports. UAS sightings were more likely to be reported close to primary airports, especially large and medium hub airports. Large and medium hub airports account for only 1.8 percent of NPIAS airports, however, they accounted for 48.9 percent of UAS sightings. Similarly, primary airports are 11.4 percent of NPIAS airports and accounted for 67 percent of all UAS sightings. Each large and medium hub airport had at least one UAS sighting, and UAS sightings at these airports would be more disruptive in terms of impacts on aircraft operations at the airport, as well as potential disruption with respect to delays propagating through the air traffic system. Sixty-six small hub airports (91.7 percent) also had at least one UAS sighting, but UAS sightings were less often reported at non-hub airports, which is consistent with the relatively few UAS sightings at commercial service airports and GA airports. Table 4.3 displays the number and percentage of UAS sighting reports by airport category.

Table 4.4 presents the top 20 airports in terms of the number of UAS sightings, which were all large hub airports. UAS sightings were more likely in populous urban areas since the top five airports (LGA, LAX, JFK, ORD, EWR) are close to the three largest cities (New York, Los Angeles, and Chicago). LaGuardia Airport had the most UAS sightings (311), followed by LAX (210 UAS sightings), and JFK (157 UAS sightings). These three airports were also top ranked when UAS sightings were normalized with respect to annual operations.

Table 4.3 UAS sighting reports by airport category (Sep. 2016 to Aug. 2019).

| Airport Category | Number of Airports in the U.S. | Examples | Number (%) of Reports | Percentage of 2016 Total Commercial Enplanements | Percentage of Total Aircraft Operations | Number (%) of Airports with UAS Sightings | Rate (UAS Sighting Reports/ Airports) |
|---|---|---|---|---|---|---|---|
| Large hub | 30 | LGA | 2,416 (36.9%) | 72.48 | 13.1 | 30 (100%) | 80.53 |
| Medium hub | 31 | IND | 783 (12.0%) | 15.87 | 4.9 | 31 (100%) | 25.26 |
| Small hub | 72 | LGB | 649 (9.9%) | 8.21 | 6.9 | 66 (91.7%) | 9.83 |
| Non-hub | 247 | EVV | 538 (8.2%) | 3.26 | 10.7 | 143 (57.9%) | 3.76 |
| Primary total | 380 | - | 4,386 (67.0%) | 99.83 | 35.6 | 270 (71.0%) | 16.24 |
| Commercial service | 126 | MWA | 52 (0.8%) | - | - | 18 (14.3%) | 2.89 |
| Reliever | 261 | TEB | 1,240 (18.9%) | - | - | 160 (61.3%) | 7.75 |
| GA | 2,554 | LAF | 432 (6.6%) | - | - | 223 (8.7%) | 1.94 |
| Non-NPIAS | 13,117 | - | 288 (4.4%) | - | - | 185 (1.4%) | 1.56 |
| Unknown | - | - | 146 (2.3%) | - | - | - | - |
| Nonprimary total | 16,058 | - | 2,158 (33.0%) | 0.13 | 64.3 | 586 (3.6%) | 3.68 |

Table 4.4 Airports with the most UAS sighting reports (Top 20, Sep. 2016 to Aug. 2019).

| Rank by Number | Airport Code | Number of UAS Sighting Reports | Airport Category | Annual Airport Operations | Rate of UAS Sighting Reports to Annual Operations (in ten-thousandth) | Rank by Rate | Nearby City | State |
|---|---|---|---|---|---|---|---|---|
| 1 | LGA | 311 | Large hub | 369,632 | 8.41 | 1 | New York | New York |
| 2 | LAX | 210 | Large hub | 701,969 | 2.99 | 10 | Los Angeles | California |
| 3 | JFK | 157 | Large hub | 458,421 | 3.42 | 7 | New York | New York |
| 4 | ORD | 116 | Large hub | 887,475 | 1.31 | - | Chicago | Illinois |
| 5 | EWR | 112 | Large hub | 446,301 | 2.51 | 20 | New York | New Jersey |
| 6 | MIA | 98 | Large hub | 414,997 | 2.36 | - | Miami | Florida |
| 7 | LAS | 92 | Large hub | 543,164 | 1.69 | - | Las Vegas | Nevada |
| 8 | DCA | 89 | Large hub | 297,829 | 2.99 | 11 | Washington D.C. | Virginia |
| 9 | ATL | 86 | Large hub | 892,810 | 0.96 | - | Atlanta | Georgia |
| 10 | IAH | 83 | Large hub | 462,716 | 1.79 | - | Houston | Texas |
| 11 | BOS | 81 | Large hub | 417,915 | 1.94 | - | Boston | Massachusetts |
| 12 | PHL | 78 | Large hub | 378,787 | 2.06 | - | Philadelphia | Pennsylvania |
| 13 | CLT | 76 | Large hub | 555,345 | 1.37 | - | Charlotte | North Carolina |
| 14 | MCO | 75 | Large hub | 347,938 | 2.16 | - | Orlando | Florida |
| 15 | DFW | 74 | Large hub | 671,799 | 1.10 | - | Dallas/Fort Worth | Texas |
| 16 | SEA | 68 | Large hub | 429,937 | 1.58 | - | Seattle | Washington |
| 17 | FLL | 66 | Large hub | 321,509 | 2.05 | - | Miami | Florida |
| 18 | DEN | 64 | Large hub | 600,529 | 1.07 | - | Denver | Colorado |
| 19 | PHX | 61 | Large hub | 432,659 | 1.41 | - | Phoenix | Arizona |
| 20 | SFO | 61 | Large hub | 463,597 | 1.32 | - | San Francisco | California |

### 4.1.2 Inferential Statistical Analysis of UAS Sighting Reports

This research developed a binary logistic regression model to explore how different factors correlated with the likelihood that a UAS sighting required an evasive action by an aircraft pilot. The independent variables shown in Table 4.5 were considered for inclusion in the model.

Table 4.5 Independent variables considered for inclusion in binary logistic regression model.

| **Potential independent variables** | **Type** | **Outcomes** |
|---|---|---|
| Month | Categorical | January to December |
| Time of day | Binary | Day, night |
| Operation type | Categorical | Commercial, GA, other |
| Airport category | Binary | Primary, non-primary |
| UAS MOR alert | Binary | Yes, no |
| LEO notification | Categorical | Yes, no, unknown |
| Altitude | Numerical | The altitude of the UAS in number |
| Proximity to airport | Numerical | Distance from the UAS sighting location to the reported airport in number |
| Proximity to manned aircraft | Numerical | Distance between UAS and manned aircraft |
| Position of UAS | Categorical | Above, below, left, right, front, behind |

All of the potential factors shown in Table 4.5 were included in the initial model, which was used to determine which variables were statistically significant. Based on the results, the three variables shown in Table 4.6 were statistically significant and included in the final model.

Table 4.6 Binary logistic regression model results.

| **Independent variable** | **Outcome** | **Coefficient** | **Chi-Square** | **Significance** |
|---|---|---|---|---|
| Constant | - | -6.212 | 0.001 | 0.975 |
| Time of day | Night | 0.377 | 5.632 | 0.018 |
| Operation type | GA | 1.207 | 16.268 | < 0.001 |
| | Other | 0.501 | | |
| Position of UAS | Below | 0.871 | 32.683 | < 0.001 |
| | Left | 1.177 | | |
| | Right | 1.534 | | |
| | Front | 3.620 | | |
| | Behind | -9.115 | | |

Note: sample size ($N$), 1,894; model −2 log likelihood, 425.503.

According to the model results, pilots were more likely to take evasive actions (indicated by the positive coefficient) at night, when the aircraft was a GA aircraft or other type of aircraft (not a commercial aircraft). This information is useful since it indicates that it may be helpful to provide educational information to GA pilots regarding the potential threat of UAS.

## 4.2 Case Study

This case study on the EWR UAS sighting event describes the operational impacts based on data collected from the FAA's OPSNET and ASPM.

### 4.2.1 Newark Liberty International Airport

Newark Liberty International Airport is a large hub airport in New Jersey (FAA, 2018a). It is one of the three major airports in the New York metropolitan area, which serves both the New York metropolitan area and New Jersey. The airport is owned jointly by the cities of Elizabeth and Newark and operated by the Port Authority of New York and New Jersey (The Port of New York and New Jersey, 2020).

Newark Liberty International Airport has three runways, including two parallel runways, 4L/22R and 4R/22L, and a crosswind runway, 11/29 (The Port of New York and New Jersey, 2020). Both 4L/22R and 4R/22L support precision instrument approaches at all four approaches. Runway 4L/22R is mainly used for takeoffs, and runway 4R/22L is mainly used for landings. Runway 11/29 supports precision instrument approaches only on runway 11, which is primarily used by smaller aircraft or when there are strong crosswinds on the two main runways.

In 2019, EWR was the fifth busiest airport in the U.S. in terms of international passenger enplanements and the 12$^{th}$ busiest airport in the country in terms of total passenger enplanements, serving about 46 million passengers (BTS, n.d. -a). According to the Port Authority of New York and New Jersey (2020), EWR handled 1,222 operations daily on average in 2019. Table 4.7 shows the statistics of on-time performance and flight delays in January 2018 and January 2019 (BTS, n.d. -b).

Table 4.7 On-time performance and flight delays at EWR.

| Time | On-time Arrivals (%) | Arrival Delays (%) | Flights Cancelled (%) | Diverted | Total Aircraft Operations |
|---|---|---|---|---|---|
| January 2018 | 7,970 (68.54%) | 2,969 (25.53%) | 680 (5.85%) | 10 | 11,629 |
| January 2019 | 6801 (64.55%) | 3,445 (32.70%) | 257 (2.44%) | 33 | 10,536 |

### 4.2.2 The UAS Sighting at EWR

On the evening of January 22, 2019, airline pilots reported a UAS in their approach path, which led the FAA to stop air traffic for 21 minutes (Shepardson, 2019; Silk, 2019). According to the FAA's spokesman Greg Martin, the agency received two reports of UAS operating near EWR at 4:44 p.m. (Aratani, 2019; Cohen, 2019). One Southwest Airlines pilot and another United Airlines pilot saw what they believed to be a UAS about 3,500 feet in the air above Teterboro, New Jersey, as they were preparing to land their aircraft at EWR. An air traffic controller who watched over EWR airspace also spotted two UAS flying dangerously close to a plane ("FAA Investigating Drone Scare", 2019). Based on the reports, inbound flights to EWR were held in the air and takeoffs were momentarily stopped as a precaution (Dow, 2019). In total, the FAA held 43 inbound flights in the air, while ten were diverted to land at other airports. Table 4.8 shows all flights that were diverted from EWR to other airports on January 22 (BTS, n.d. -c). Another 170 EWR-bound planes were briefly delayed on the ground before takeoff at other airports located around the country. Normal operations resumed at around 7 p.m. (Law, 2019).

Table 4.8 Flights diverted from EWR to other airports on January 22.

| Airline Code | Flight Number | Origin | Final Destination |
|---|---|---|---|
| WN | 788 | DEN | ALB |
| EV | 4155 | IND | BWI |
| AA | 714 | CLT | PHL |
| B6 | 1044 | PBI | JFK |
| YX | 3528 | EYW | IAD |
| YX | 3548 | MSY | PHL |
| YX | 3565 | MCI | PIT |
| UA | 1235 | TPA | IAD |
| UA | 645 | JAX | PHL |
| UA | 443 | IAH | IAD |

The EWR stoppage was the first time that action was taken at a major U.S. airport due to an unauthorized UAS operation in the vicinity (Silk, 2019). The stoppage was relatively brief, and it only caused an average delay of approximately one hour, however, it provides an excellent opportunity to investigate the impact on not only EWR but also on other airports.

### 4.2.3 Newark Liberty International Airport Aircraft Operation and Delay Data Analysis

Aircraft operation and delay data are collected by the FAA, and published through the OPSNET and the APSM. This analysis considers data for EWR, John F. Kennedy International Airport (JFK), and LGA on January 22, 2019, as well as EWR data one week and one month before and after the event on December 22, 2018, January 15, 2019, January 29, 2019, and February 22, 2019.

#### 4.2.3.1 Descriptive Statistical Analysis of Newark Liberty International Airport Data

Consider operating characteristics on the day a UAS sighting disrupted aircraft operations at EWR. According to the FAA data, EWR handled 1,228 flights on January 22, 2019, and 67 of 1,228 flights were delayed. These delays accounted for 5.46 percent of all aircraft operations that day. The average minutes of delays were 60 minutes. To provide some context for the delays on this date, Table 4.9 also shows aircraft operations and delays at EWR one month and one week before and after the event. As shown in Table 4.9, The mean percent of delays on these five days is 9.25 percent. On the day of the UAS sighting occurred (1/22/2019), the percent of aircraft operation delays at EWR is 3.79 percent less than the average. The mean of the average minutes of delays is 59.51 minutes on these five days, which is very close to the average minutes of delays on January 22, 2019.

Table 4.9 Aircraft operations and delays at EWR by date.

| Date | Total Operations | Total Delays | Percent of Delays | Average Minutes of Delays |
|---|---|---|---|---|
| 12/22/2018 | 1,282 | 77 | 6.01% | 55 |
| 1/15/2019 | 1,226 | 57 | 4.65% | 19 |
| 1/22/2019 | 1,228 | 67 | 5.46% | 60 |
| 1/29/2019 | 1,150 | 269 | 23.39% | 78 |
| 2/22/2019 | 1,278 | 100 | 7.82% | 36 |
| Average | 1,232.8 | 114 | 9.25% | 59.51 |

Delays are classified into different categories by the FAA. The FAA classifies the causes of NAS delays into five categories: weather, volume, equipment, runway, and other (FAA, n.d. -c). Delay caused by a UAS sighting is considered other delay. Figure 4.12 shows delays at EWR by cause.

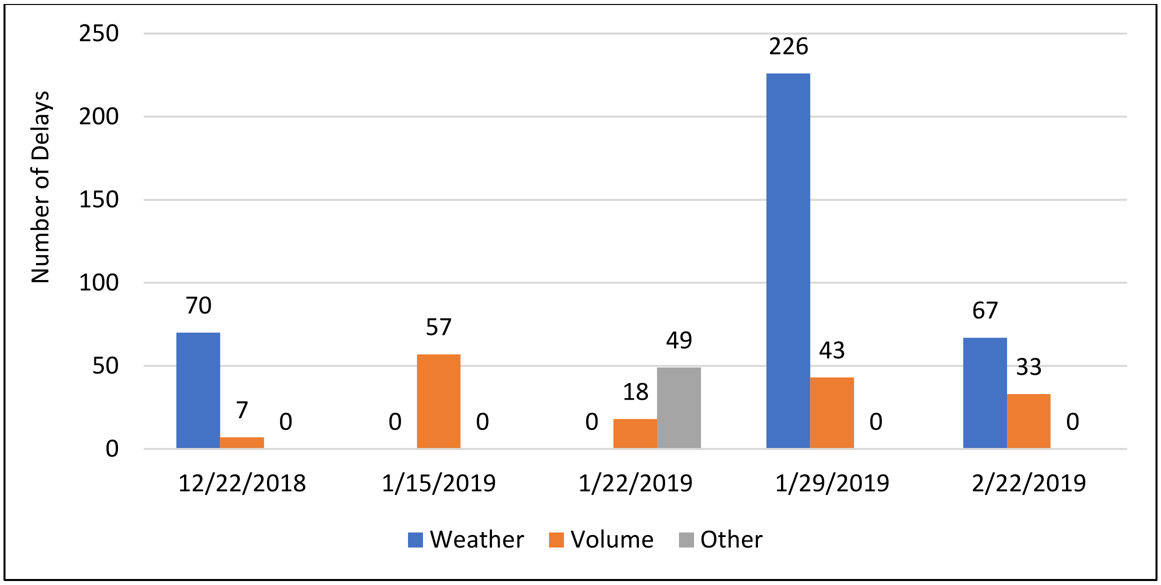



Figure 4.12 Delays at EWR by cause.

Though the EWR UAS sighting caused delays for aircraft operations, the number of delays that resulted from the UAS sighting is much less than the number of delays due to weather on three out of the five days shown in Figure 4.12. Comparing the number of delays by cause (shown in Figure 4.12) with the delays by cause for the entire year (shown in Figure 4.13), it can be seen that the weather delays on December 22, January 29, and February 22 are consistent with the fact that weather is responsible for the majority of delays in 2019; 85 percent of all delays in 2019 were caused by weather. The next leading cause of delays after weather in the sample shown in Figure 4.12 is volume, which is again consistent with the data shown in Figure 4.13 for the entire year. Although "Other" delay, specifically delays due to a UAS sighting, is the leading cause of delay on January 22, this is the only day among these five days considered that EWR had delays due to "Other" reasons. Figure 4.13 indicates that "Other" delay is the least likely cause of delay during 2019.

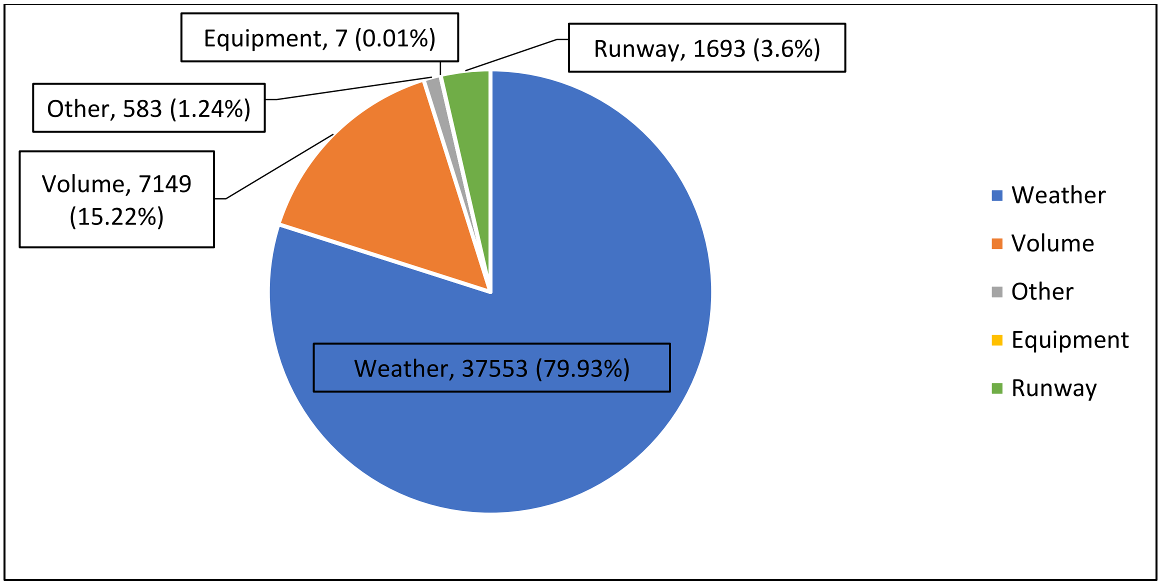



Figure 4.13 Distribution of delays by cause at EWR in 2019.

The impact of delays on airports is not only affected by the number of delays and the cause of the delay, but also by the length of delays. Figure 4.14 shows the average length of delay in minutes of delays for each kind of delay that was observed. Results are shown for EWR on January 22, as well as one week and one month before and after, as well as for JFK and LGA on January 22.

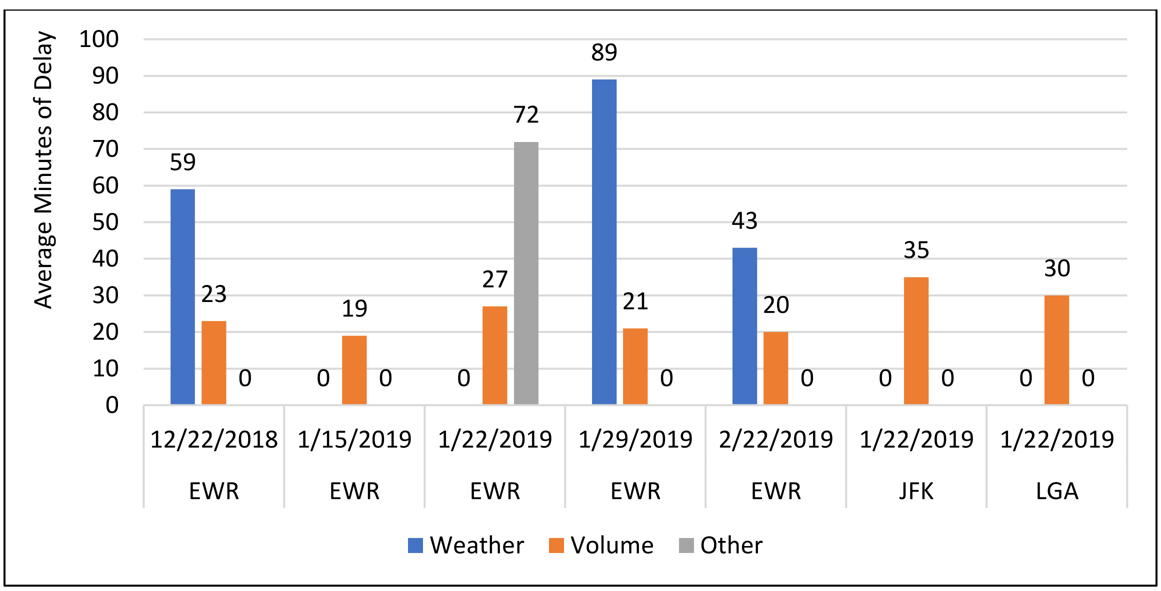



Figure 4.14 Average minutes of delays by cause.

Figure 4.14 shows that the delays caused by weather resulted in longer delays than the delays caused by volume constraints; all weather-related delays were longer than volume-related delays at EWR, JFK, and LGA. At EWR, the average length of a weather delay was 75 minutes on these five days, while the average length of a volume delay was 21 minutes (FAA, n.d. -j); these numbers were calculated by summing the time of all delays due to weather or volume cause and divided by the number of weather or volume delays. On January 22, the length of a delay due to other causes was 72 minutes, which is close to the average length of weather delays on December 22, January 29, and February 22, and much longer than the average volume delay for this data set shown in Figure 4.14.

In addition to the categorization of delays by cause, the FAA also classifies delays based on the type of operations that are affected; categories include air carrier, air taxi, GA, and military. Figure 4.15 shows the distribution of the aircraft operations affected by delay at EWR in 2019 (FAA, n.d. -j).

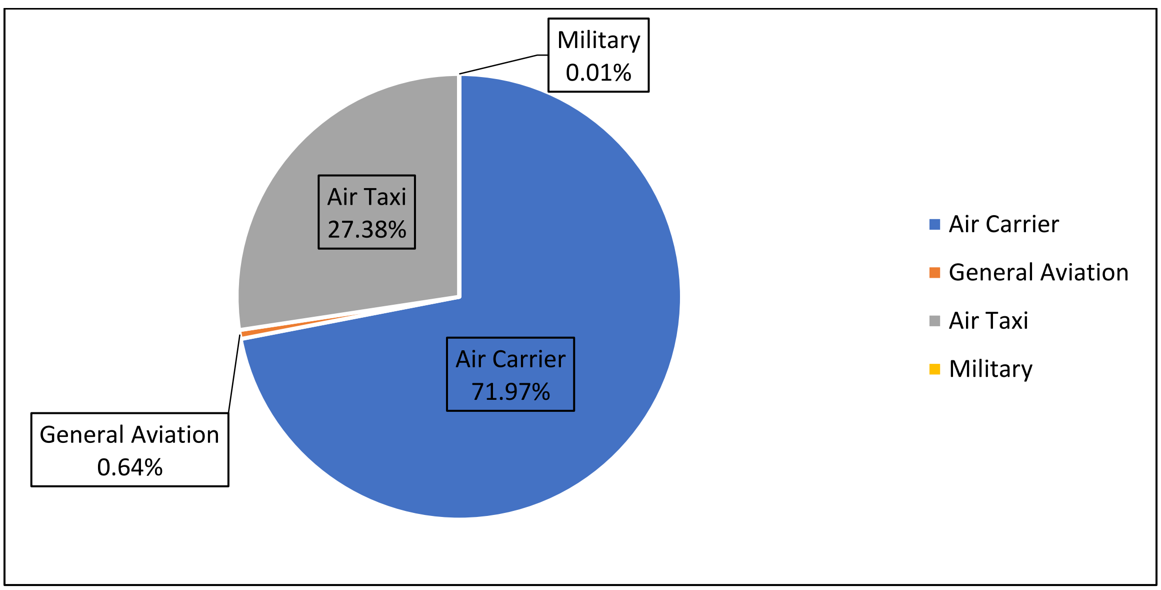



Figure 4.15 Distribution of delay by class at EWR in 2019.

In 2019, 71.97 percent of the delays at EWR were for commercial air carrier aircraft, and 27.38 percent of all delays were air taxi. The sum of delays to GA and military flights were less than one percent of all delays. On January 22, 2019 at EWR, air carrier delays and air taxi delays were 57 and 43 percent, respectively, of all delays. The percent of air carrier delays at EWR on January 22 is much lower than the average of 2019. Meanwhile, the percent of air taxi delays is more than double the average of 2019. Hence, the EWR UAS sighting caused more delays to air taxi. It is likely that flights operated by air carrier have a higher priority than air taxi flights once operations resume. Figure 4.16 shows the delays at EWR by class.

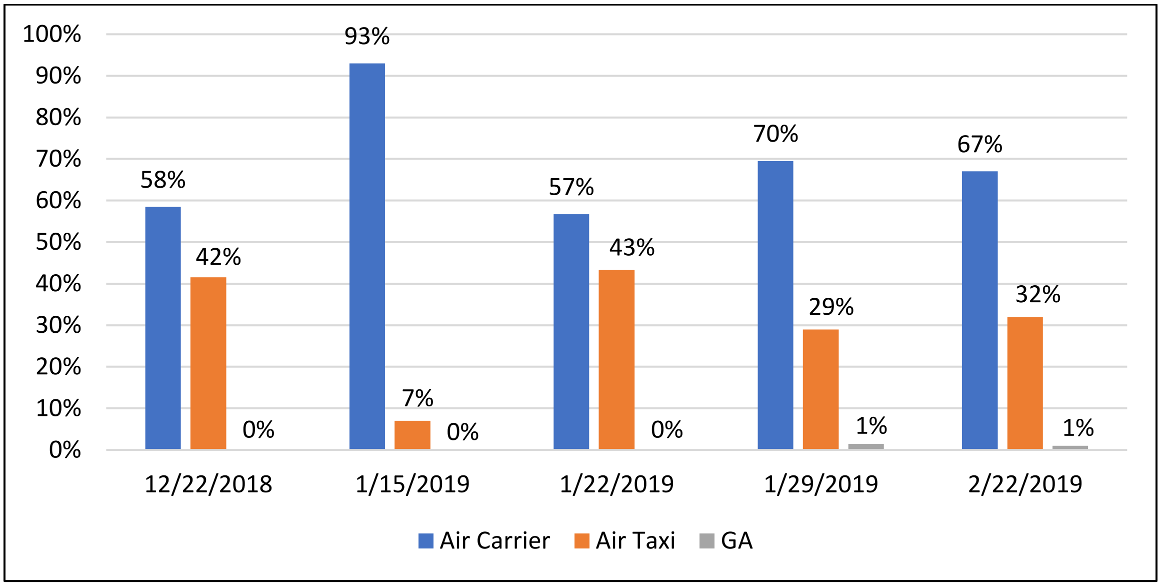



Figure 4.16 Delays at EWR by class.

#### 4.2.3.2 Descriptive Statistical Analysis of New York Metropolitan Area Airport Data

There are five airports located in the New York metropolitan area, including EWR, JFK, LGA, TEB, and New York Stewart International Airport (Port of New York and New Jersey, 2019). Based on the airport annual passenger enplanements, EWR, JFK, and LGA are large hub airports; New York Stewart International Airport is a non-hub airport; TEB is a reliever airport. In this case study, aircraft operations and delays at EWR, JFK, and LGA are analyzed and shown in Table 4.10.

Table 4.10 Aircraft operations and delays by airport for large hub airports in New York.

| **Aircraft operations and delays** | **Date or daily average** | **Airport** | | |
|---|---|---|---|---|
| | | EWR | JFK | LGA |
| Aircraft Operations | January 22, 2019 | 1,228 | 1,181 | 1,157 |
| | Daily Average in January 2019 | 1,133 | 1,197 | 962 |
| Delays | January 22, 2019 | 67 | 5 | 13 |
| | Daily Average in January 2019 | 149 | 34 | 174 |
| Percent of Flights Delayed | January 22, 2019 | 5.46% | 0.42% | 1.12% |
| | Daily Average in January 2019 | 13.19% | 2.80% | 18.07% |
| Average Minutes of Delay | January 22, 2019 | 60 | 175 | 390 |
| | Daily Average in January 2019 | 149 | 34 | 174 |

Consider operating characteristics at EWR, JFK, and LGA on January 22 compared to other days that month. The number of aircraft operations at EWR was eight percent higher than average, and the number of aircraft operations at LGA was 20 percent higher than average, whereas the number of operations at JFK was within one percent of the average. Both JFK and LGA are slot restricted airports, which means that the FAA uses assigned runway slots to limit scheduled air traffic since there are capacity constraints. The only other slot restricted airport in the U.S. is Ronald Reagan Washington National Airport.

As shown in Table 4.10, EWR had 67 delays on January 22. Although the number of delays at EWR was much higher than at either JFK or LGA, the number of delays on January 22 was much lower than on an average day in January at EWR. The average length of delays on January 22 at EWR was also much lower than the average for January (less than half), although the average length of delays at JFK and LGA were much higher than the average for January. At EWR, there were 18 volume delays on January 22, and the remaining 49 delays were classified as "Other" delays (the delay due to the UAS sighting was included in this classification).

At EWR, JFK, and LGA, the percentage of flights that were delayed is lower than the daily average for the month. The average delay in minutes for all flights in January 2019 varies greatly from airport to airport. The average time length of delays at JFK is 34 minutes, however, both EWR and LGA recorded an average over two hours. One possible explanation for the difference is that JFK has more international flights than EWR and LGA, and the on-time performance of international flights is better than domestic flights.

#### 4.2.3.3 Inferential Statistical Analysis of Aircraft Operation and Delay Data

Airport operations data of EWR, JFK, and LGA, as well as data on different days (January 22, and one week and one month before and after) are compared through paired sample t-tests. To calculate the difference between paired observations on the same measurement variable, observations are paired based on the date and airport. In all t-tests, the baseline observation reflects the operations at EWR on January 22, 2019, the day on which the UAS sighting occurred. The other data point reflects operations at another airport on this day or at EWR on another day (December 22, 2018, January 15, 2019, January 29, 2019, or February 22, 2019). For example, the mean of the taxi out delay at EWR on January 22, 2019, is compared to the mean of the taxi out at EWR on January 15, 2019. The means of the measurement variables shown in Table 4.11 were tested with the t-stat, and the means and variances for each measurement variable are presented in Table 4.11.

Table 4.11 Means and variances of measurement variables.

| Measurement Variable | Mean and Variance | Airport and Date | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | EWR 1/22/2019 | EWR 12/22/2018 | EWR 1/15/2019 | EWR 1/29/2019 | EWR 2/22/2019 | JFK 1/22/2019 | LGA 1/22/2019 |
| Gate Departure Delay | Mean | 22.47 | 22.03 | 9.02 | 20.62 | 11.15 | 10.68 | 18.69 |
| | Variance | 222.29 | 18.98 | 15.41 | 19.65 | 3.31 | 4.62 | 140.31 |
| Average Taxi Out Time | Mean | 23.17 | 21.38 | 24.85 | 21.63 | 25.24 | 20.75 | 22.24 |
| | Variance | 11.99 | 5.20 | 5.09 | 3.67 | 16.08 | 0.73 | 5.05 |
| Taxi Out Delay | Mean | 10.27 | 8.46 | 11.92 | 8.84 | 12.25 | 3.90 | 9.17 |
| | Variance | 12.23 | 4.92 | 5.03 | 3.49 | 15.62 | 0.57 | 4.71 |
| Airport Departure Delay | Mean | 30.67 | 29.10 | 17.64 | 27.64 | 20.42 | 12.89 | 25.69 |
| | Variance | 217.38 | 31.80 | 11.95 | 25.28 | 30.43 | 3.56 | 180.29 |
| Airborne Delay | Mean | 21.32 | 6.80 | 6.19 | 8.46 | 4.17 | 3.69 | 4.30 |
| | Variance | 43.37 | 28.74 | 6.32 | 20.34 | 0.60 | 2.29 | 1.07 |
| Taxi In Delay | Mean | 4.63 | 5.42 | 3.72 | 3.11 | 4.41 | 3.11 | 5.72 |
| | Variance | 4.42 | 1.95 | 1.22 | 1.01 | 2.95 | 2.07 | 0.21 |
| Block Delay | Mean | 23.09 | 7.80 | 6.64 | 11.82 | 4.77 | 2.59 | 6.92 |
| | Variance | 21.20 | 36.57 | 0.25 | 1.31 | 3.96 | 3.48 | 14.52 |
| Gate Arrival Delay | Mean | 37.11 | 23.35 | 9.28 | 40.88 | 13.87 | 7.00 | 15.10 |
| | Variance | 65.93 | 67.25 | 11.97 | 46.92 | 52.39 | 9.74 | 30.94 |
| Percent of Delayed Gate Departures | Mean | 34.53 | 37.85 | 16.90 | 36.96 | 23.38 | 22.49 | 27.36 |
| | Variance | 174.83 | 92.13 | 19.69 | 25.73 | 10.05 | 8.97 | 196.14 |
| Average Minutes of Delay Per Delayed Gate Departure | Mean | 57.84 | 54.43 | 51.36 | 53.91 | 44.09 | 43.10 | 59.22 |
| | Variance | 263.90 | 26.96 | 509.03 | 206.38 | 65.01 | 54.13 | 302.00 |
| Percent of Delayed Gate Arrivals | Mean | 52.81 | 37.72 | 24.23 | 61.65 | 22.80 | 11.70 | 30.24 |
| | Variance | 305.50 | 32.91 | 36.17 | 73.09 | 108.99 | 14.51 | 77.87 |
| Average Minutes of Delay Per Delayed Gate Arrival | Mean | 72.51 | 59.48 | 32.16 | 64.46 | 53.10 | 50.75 | 44.93 |
| | Variance | 356.65 | 550.90 | 65.57 | 11.93 | 198.24 | 525.88 | 102.46 |
| Percent of On-Time Gate Departures | Mean | 65.47 | 62.15 | 83.10 | 63.05 | 76.62 | 77.52 | 72.64 |
| | Variance | 174.83 | 92.13 | 19.69 | 25.71 | 10.05 | 8.97 | 196.14 |
| Percent of On-Time Airport Departures | Mean | 52.56 | 46.22 | 66.26 | 49.31 | 54.98 | 72.57 | 61.11 |
| | Variance | 198.22 | 129.56 | 47.52 | 28.64 | 287.67 | 11.77 | 77.15 |
| Percent of On-Time Gate Arrivals | Mean | 47.20 | 62.28 | 75.78 | 77.21 | 77.21 | 88.30 | 69.77 |
| | Variance | 305.50 | 32.91 | 36.17 | 108.99 | 108.99 | 14.51 | 77.87 |

Table 4.12 shows the results of the t-tests in which there is a statistically significant difference between the two means for $\alpha = 0.05$. In each case, the mean of each group reflects the average of the measurement variable between 4 p.m. and 7 p.m. ($n = 4$) and the degree of freedom is three ($n - 1 = 3$).

Table 4.12 Results of t-tests.

| **Variables** | **Airport and Date** | | | | | |
|---|---|---|---|---|---|---|
| | EWR 12/22/2018 | EWR 01/15/2019 | EWR 01/29/2019 | EWR 02/22/2019 | JFK 01/22/2019 | LGA 01/22/2019 |
| Airborne Delay | | | | | | |
| t Stat | -5.34 | -6.67 | -3.20 | -5.29 | -6.92 | -5.19 |
| p-value | 0.01 | 0.01 | 0.05 | 0.01 | 0.01 | 0.01 |
| Block Delay | | | | | | |
| t Stat | -5.45 | -7.90 | -5.69 | -11.79 | -12.05 | -4.92 |
| p-value | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.02 |
| Taxi Out Delay | | | | | | |
| t Stat | | | | | -4.29 | |
| p-value | | | | | 0.02 | |
| Taxi In Delay | | | | | | |
| t Stat | | | | | -3.68 | |
| p-value | | | | | 0.03 | |
| Gate Arrival Delay | | | | | | |
| t Stat | -4.31 | -8.59 | | -5.01 | -6.96 | -3.56 |
| p-value | 0.02 | 0.00 | | 0.02 | 0.01 | 0.04 |
| Percentage of Delayed Gate Arrivals | | | | | | |
| t Stat | | -4.18 | | -4.57 | -5.24 | |
| p-value | | 0.02 | | 0.02 | 0.01 | |
| Average Minutes of Delay Per Delayed Gate Arrival | | | | | | |
| t Stat | | -4.05 | | | -5.51 | |
| p-value | | 0.03 | | | 0.01 | |
| Percentage of On-Time Gate Arrivals | | | | | | |
| t Stat | | 4.18 | 4.57 | 4.57 | 5.24 | |
| p-value | | 0.02 | 0.02 | 0.02 | 0.01 | |

According to the results of t-tests, the airborne delay on January 22 at EWR is statistically significantly different from all other days and all other airports since all p-values of the airborne delay are no more than 0.05. The t-stat values suggest that the UAS sighting resulted in significantly more airborne delays. Similarly, the group mean of block delay on January 22 at EWR is also statistically significantly different from the group means of block delay at another airport or on another day, which means there were more block delays on January 22 at EWR, and the UAS sighting caused more block delays.

Next, the group means of the taxi out delay and the taxi in delay at EWR and JFK on January 22 are statistically significantly different; the p-value of taxi out delay is 0.02, and the p-value of taxi in delay is 0.03, both of which smaller than 0.05. As the t-stat values of taxi out delay and taxi in delay are -4.29 and -3.68 respectively, they indicate that there were fewer taxi out and taxi in delays at JFK than EWR on January 22.

In addition, the gate arrival delay, the percentage of delayed gate arrivals, the average minutes of delay per delayed gate arrival, and the percentage of on-time gate arrivals on January 22 at EWR are significantly different from some days or other airports. It could be concluded that the EWR UAS sighting caused more gate arrival delays, but other types of delays could also cause gate arrival delays. For example, the gate arrival delay on January 22 at EWR is not significantly different from the date arrival delay on January 29 at EWR, however, 89 of 110 delays on January 29 at EWR were caused by weather, and there is no delay caused by “Other” reason on that day.

Last but not least, while comparing JFK with EWR and LGA, JFK performs better on on-time flights since the group means of variables (shown in Table 4.12) at JFK are significantly different from all other airports and dates. These results are also consistent with the data in Table 4.10 which show that the number of delays and percent of flights that were delayed at JFK are much lower than EWR and LGA.

To sum, section 4.2 provided an in-depth analysis of the EWR UAS sighting on January 22, 2019. This section answered the second research question by discussing the operational impacts of a UAS sighting on an airport through descriptive and inferential statistical analysis. In the next section, the researcher will present the results of interviews with airport personnel, which show airport management’s current perspective on UAS sightings at airports.

## 4.3 Interviews

Five phone interviews lasting between 15 and 35 minutes were conducted with airport managers and an airport operations supervisor in the summer of 2020 to understand the perspectives of airport personnel regarding UAS sightings and the potential for UAS to be used for airport operation activities. The airport managers at Purdue University Airport (LAF), EVV, and Huntingburg Regional Airport (HNB) were interviewed, as well as the airport senior director of operations at IND and the airport operations supervisor at an international small hub airport. All research participants were provided with identical interview questions shown in Appendix D. Interview notes are shown in Appendix E. A summary of interview results is presented in Table 4.13.

Table 4.13 Results of interviews.

| **Airport** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **Background information** | | | | | |
| Part 139 Airport | Yes | Yes | No | Yes | Yes |
| NPIAS category | GA | Non-hub | GA | Medium hub | Small hub |
| UAS sightings in FAA database (September 2016 to August 2019) | 1 | 4 | 0 | 11 | 5 |
| **Interview results** | | | | | |
| UAS sightings reported to the airport | 0 | 0 | 0 | 0 | 1 |
| UAS found on airport property | 0 | 1 | 0 | 2 | 0 |
| Experience with law enforcement department(s) relative to UAS | No | Yes, with county sheriff, state police, and FBI | Yes, city police and county sheriff | FBI, ATF, Indianapolis metropolitan police department | No |
| Experience with FAA UAS sighting database | No | No | No | Yes, heard of the database | No |
| Experience with FAA wildlife strike database | Yes, filled reports | Yes, using a computer system to track wildlife strikes | Yes, used the database | Yes, filled reports | Yes, heard of the database |
| UAS surveillance in training, operations, or communications | No plans to include | A part of the daily airfield training | Through informal communications | A part of the airport operations training for managers | No plans to include |
| Wildlife surveillance in training, operations, or communications | No plans to include | Training for wildlife surveillance | Training for wildlife surveillance | Annual recurrent wildlife training | Wildlife training for airport operation officers and maintenance personnel |
| Perceived risk of UAS sightings | Neutral | Regular: low to neutral; targeted: very low | Low | Very low | Low |
| Perceived risk of wildlife strikes | Neutral | Neutral | Neutral to high | Low | Neutral |
| Investigation on airport UAS detection technologies | Not yet | Not yet | Not yet | In the early process | Not yet |
| Tactical Response Plan for UAS sightings | Not yet | Yes | Not yet | Yes | Not yet |
| Using AEP for coping with UAS sightings or UAS strikes | N/A | N/A | Somewhat effective | N/A | Somewhat effective |
| Using UAS to support airport operations | Very interested | Moderately interested | Very interested | Moderately interested | Moderately interested |

#### 4.3.1 UAS Sighting at Airports

According to the interview results, four of the five airports were not aware of FAA's UAS sighting database and did not receive notification or reports of any UAS sightings at their airports. UAS sightings had been reported to the FAA for three of the four airports. This result indicates that airports are not notified of UAS sightings, either when they occur or when they are entered into the database.

Although UAS sightings had not caused negative impacts on flights or operations at these airports, larger airports, such as IND, have developed comprehensive response plans to cope with UAS sightings, per federal requirements since UAS sightings would be more disruptive at medium and large hub airports. At IND, the alert warning system (AWS) group is responsible for UAS sightings. The AWS group is made up of officers from TSA, FAA, FBI, Bureau of Alcohol, Tobacco, Firearms and Explosives, U.S. Customs and Border Protection, and Indianapolis metropolitan police department. When a UAS is spotted flying around the airport, the airport will be contact by the AWS group, and the TSA officer will notify everyone in the group. The AWS group will then respond to the event in coordination with appropriate partners; response will include looking for and locating the operator, and getting the UAS out of the air as quick as possible. Meanwhile, the airport operations department will contact the airport traffic control tower, and the airport will also notify airlines of the UAS sighting since flight schedules may be disrupted temporarily until the issue is resolved. The airport public affairs department will use social media to provide public information, as well as notify the local news media, if the event is going to be extended. Indianapolis Metropolitan Police department may use its own UAS to find the operator. Overall, with support from the different disciplines, the airport will be able to handle the UAS sighting effectively and minimize the impact of a UAS sighting on airport operations.

GA airports currently rely on the general AEP in the event of a UAS sighting, and have not developed a detailed response plan for UAS sightings; this is probably adequate, since UAS sightings are less frequent at these smaller airports, and since the operational impacts are less severe since there are no scheduled commercial flights.

From the airport standpoint, the risk associated with a UAS sighting was considered relatively low compared with the risk of wildlife strikes, mainly because of the lower frequency of UAS sightings relative to wildlife strikes. The threat due to UAS sightings was considered very low to neutral, whereas the threat due to wildlife strikes ranged from low to high (the scale was a five point scale: very low, low, neutral, high, and very high).

Airport personnel had more experience with the FAA Wildlife Strike Database than with the UAS sighting database. All airport personnel knew of the Wildlife Strike Database, whereas only one person had heard of the UAS sighting database. Similarly, training for wildlife inspections was conducted at all five airports, although most airports did not provide specific training for UAS surveillance; some airports would address it as part of the general hazards in the airport operation trainings.

Overall, airports had much more experience with wildlife management due to the higher frequency of wildlife strikes and the Part 139 requirement for a Wildlife Hazard Management plan. UAS sightings are a new threat to aviation safety, a low risk at many airports, and can usually be accommodated by the existing airport operations training and AEP.

#### 4.3.2 Application of UAS for Airport Operations

All airports have some interest in using UAS for airport operations. Applications include pavement inspections, perimeter inspections, airport facility inspections, visual inspections of off-airport properties (for Part 77), lightning system inspections, wildlife inspections, and photo and documentation of airport construction projects.

Some airports have conducted some pilot studies that have used UAS for airport operations activities. One example of a pilot study is a GA airport that used UAS to check precision approach path indicator (PAPI), a visual aid that provides guidance information to help a pilot acquire and maintain the correct glide slope when approach the airport (FAA, 2019c). There are several advantages of using a UAS to inspect PAPI. Firstly, it is budget-friendly to use a UAS. The cost of a UAS with a camera is about $2,000 and the operating cost for a UAS is very low, much less expensive than using an aircraft to carry out the same inspection. Due to the cost advantages of using UAS, inspections can be conducted more often. Furthermore, UAS capabilities are helpful for inspections. UAS can be easily stopped while flying and remain stationary in the air, and it is easy to adjust the camera angle of a UAS while flying. Inspectors on the ground can have real-time information and inspection results. In general, the cost advantage and capabilities make UAS a valuable tool for a variety of airport inspections.

## 4.4 Summary

This chapter provided in-depth analysis of UAS sightings, the EWR UAS sighting event, and the results of interviews with airport personnel. The three sections answered the three research questions. In the next chapter, a summary of research findings, discussions of results, and recommendations for future studies will be presented.

# CHAPTER 5. DISCUSSIONS AND CONCLUSIONS

This chapter summarizes the study findings and discusses the results in the context of the research questions and previous studies of UAS sightings. Finally, future research related to UAS sightings at airports and conclusions are presented.

## 5.1 Summary of the Study

Due to the increasing prevalence of UAS in recent years, UAS sightings have become a potential threat to airports. When UAS appear in the vicinity of airports, they present safety concerns and may result in negative operational and economic impacts on airports as demonstrated by numerous incidents involving UAS-related disruptions at major airports around the world. Since the FAA's mission is to provide the safest and most efficient aerospace system in the world (2019a), there is a need for research regarding the threat of UAS sightings to airports. Since UAS and sightings are a fairly new threat, previous research has been limited. To address the research gap, the research described in this dissertation was conducted to accomplish three goals: the first goal was to understand the characteristics of UAS sightings, the second goal was to understand the impact of a UAS sighting on airport operations, and the third goal was to understand the current perspective of airport personnel regarding the risk of UAS at airports. A mixed-method approach was used, incorporating both qualitative and quantitative research methods.

To address the first research question, 6,551 UAS sightings reported between September 2016 and August 2019 were analyzed. First, a qualitative data analysis methodology was adopted to synthesize the narrative component of the UAS sighting reports and develop a robust database. Ten criteria reflecting the characteristics of UAS sightings were applied to extract relevant information from the UAS sighting reports. Qualitative review of UAS sighting reports resulted in documentation of the following characteristics:

- Temporal considerations
    - UAS sightings generally vary by time of year and time of day. The most UAS sightings were reported in June, UAS sightings tapered off in the fall, and were lowest in the winter; UAS sightings began to increase again in the spring. The top

three months for UAS sighting reports were June, July, and May. The majority of UAS sightings occurred during the daytime.

- Reporting and response
  - Most of the UAS sightings (93.5 percent) were reported by pilots. Concerned citizens, airport officers, LEOs, passengers, air traffic controllers and others also reported UAS sightings, but collectively represented only 6.5 percent of the reports submitted.
  - Pilots of GA aircraft and business jets reported more UAS sightings (43.3 percent) than commercial pilots, although GA account for only 16.0 percent of operations. Pilots of large commercial aircraft reported 37.6 percent of UAS sightings, although commercial operations account for 61.2 percent of all operations.
  - In three-quarters of UAS sightings, law enforcement (e.g., airport police, local police, county sheriff, or state police) was notified or follow up actions were taken by relevant departments.
  - Mandatory occurrence report alerts were issued for 86.2 percent of the UAS sightings.
- UAS altitude and position
  - Only nine percent of the UAS were operated at or below the maximum altitude of 400 feet per 14 CFR Part 107 regulations, for the UAS sighting reports that included an altitude (87 percent of all UAS sightings). The average altitude for UAS sightings was 3,355 feet, and the median altitude was 2,200 feet.
  - Fifty-eight percent of UAS sighting reports included position of the UAS relative to the manned aircraft. Most reports indicated that the UAS was below the aircraft (39.7 percent), and the least reported position of the UAS was behind the aircraft (0.7 percent).
- Threat to manned aircraft
  - For UAS sightings in which the distance from the manned aircraft to the UAS was recorded (78 percent of all UAS sightings), 90 percent were within 1,000 feet of the aircraft, and 78 percent indicated that the UAS was within 500 feet of the aircraft. The median distance of the UAS relative to an aircraft was 200 feet, and

the average horizontal distance of 1,000 feet between the UAS and the aircraft. This proximity implies a very real threat to aircraft operations.

  - Pilots only took evasive actions in only 3.3 percent of the UAS sightings. General aviation aircraft and helicopters were more likely to take evasive actions than commercial aircraft.

- Proximity to airports
  - Generally, UAS sightings beyond 10 miles of an airport occurred at higher altitudes than UAS sightings within 10 miles of an airport.
  - For the UAS sightings in which the distance from an airport was recorded (72 percent of all UAS sightings), 57 percent occurred within five miles of the reported airport. The average distance from an airport was 6.94 miles, and the median was five miles.
  - UAS sightings were more likely to be reported close to primary airports, especially large and medium hub airports. Large and medium hub airports account for only 1.8 percent of NPIAS airports, however, they accounted for 48.9 percent of UAS sightings. The top 20 airports (in terms of the number of UAS sightings) were all large hub airports.
  - States that have large populations and cities with high population densities had more UAS sightings.

One of the greatest concerns related to UAS is the threat to manned aircraft. A binary logistic regression model was developed to identify variables that correlated with the likelihood that an evasive maneuver was required by the pilot of an aircraft that had a UAS sighting. The model results indicate that there are three significant independent variables that increase the need for an evasive maneuver.

- Position: Pilots were more likely to take evasive actions when the UAS was in front of the manned aircraft.
- Type of operation: GA pilots and pilots who conducted "other" types of operations were more likely to take evasive actions that commercial pilots.
- Time of day: The need for evasive actions was higher at night. This may be because the UAS could not be seen until the aircraft was closer.

Investigation to address the second research question included analysis and documentation of the impact of the UAS sighting that occurred at EWR on January 22, 2019. The UAS sighting led the FAA to stop air traffic for 21 minutes, and resulted in 43 inbound flights holding in the air, 10 flight diversions, and 170 EWR-bound planes briefly delayed on the ground before takeoff at other airports. Analysis included comparisons of data for EWR, JFK, and LGA on January 22, 2019; and comparisons of data for EWR on January 22, 2019 with data for EWR one week and one month before and after the event (December 22, 2018; January 15, 2019; January 29, 2019; and February 22, 2019). Descriptive and inferential statistical analysis suggest the following impacts on airport operations due to the UAS sighting:

1. The delay due to the UAS sighting was consistent with delays often encountered. On January 22, 5.5 percent of the aircraft at EWR experienced delay; this is less than 9.3 percent delayed in the sample that includes a week and a month before and after the UAS sighting. Similarly, the duration of aircraft delay was consistent with delays often encountered. On January 22, the average aircraft delay was 55 minutes, which is consistent with an average of 60 minutes considered the sample that includes a week and a month before and after the UAS sighting.
2. The number of delays that resulted from the UAS sighting is much less than the number of delays due to weather or volume. Delay due to a UAS sighting is considered “other” delay. The average duration of delay caused by “other” was close to delays caused by weather, but longer than delays caused by volume constraints. At EWR, the average length of a weather, “other”, and volume delay was 75 minutes, 72 minutes, and 21 minutes, respectively.
3. The UAS sighting caused more delays to air taxi operations than to air carrier operations. Comparing the delay at EWR on January 22 to the delay at EWR in all of 2019, air carrier delays were 57 percent on January 22 and 72 percent in 2019, and air taxi delays were 43 percent on January 22 and 27 percent in 2019. Presumably air traffic controllers prioritized service to air carriers to reduce delays for scheduled carriers, since delays for scheduled service can propagate beyond the airport.
4. The UAS sighting resulted in significantly more airborne delays and block delays compared to operations at EWR on others day and compared to operations at JFK and LGA.

Fortunately, the overall impact of the disruption caused by the UAS sighting at EWR was not inconsistent with other common airport delays, such as delays due to weather and volume.

To answer the third research question, the researcher interviewed five airport personnel at five airports. These interview results provided the perspective of airport personnel regarding UAS and the findings included:

1. Airports may not be notified of the UAS sighting when it occurs or when it is published in the FAA UAS sighting database.
2. Lager commercial airports have developed comprehensive response plans to cope with UAS sightings; smaller GA airports currently rely on the general AEP.
3. The risk associated with a UAS sighting was considered relatively low compared with the risk of wildlife strikes.
4. Airport personnel had much more experience with wildlife management than UAS sightings, and are more aware of the Wildlife Strike Database than the UAS sighting database.
5. Airport personnel are interested in using UAS for variety of airport activities, which reflects the fact that UAS provide advantages both in terms of costs and capabilities.

## 5.2 Discussion of Results

This section first provides a discussion of the research findings and how they relate to previous studies. This section also provides discussions regarding the UAS sighting database and UAS sightings at airports.

### 5.2.1 Characteristics of UAS Sightings

The characteristics of UAS sightings found in this research are generally consistent with previous studies. This research confirmed previous findings by Gettinger and Michel (2015) that UAS sightings were most likely to occur during daytime, and that pilots of GA aircraft were much more likely to report UAS sightings (54 percent) than commercial aircraft (33 percent). Both studies also found that about 60 percent of UAS sightings occurred within five miles of an airport, and the reported altitudes of UAS were higher when they were farther from an airport. This research found that the average altitude of UAS sightings with a recorded airport distance of more than 10 miles was 6,076 feet, and the average altitude within 10 miles was 2,692 feet. Both studies also found less than 10 percent of UAS sightings occurred at or below the FAA's 400-foot ceiling under 14 CFR Part 107, which is much lower than the result of the UAST study (2017) that found almost 30 percent of UAS sightings were at or below 400 feet. All three studies found that pilots took evasive action in about three percent of the UAS sightings (Gettinger & Michel, 2015; UAST, 2017). Moreover, the results of this research identified the top six airports for UAS sightings as LGA, LAX, JFK, ORD, EWR, and MIA, which is consistent with the top four cities identified by Gettinger and Michel (2015): New York/Newark, Los Angeles, Miami, and Chicago. This research found that states with the largest populations and cities with higher population densities had more UAS sightings; this is consistent with previous findings that the top 10 cities for UAS sightings had populations over 200,000 (Gettinger and Michel, 2015).

One notable difference is that this research found that 78 percent of UAS sighting reports indicated the UAS was within 500 feet of the aircraft, this is much higher than the values of 26 percent (Gettinger & Michel, 2015) and 16 percent (UAST, 2017). The increasing incidence of UAS in relatively close proximity to aircraft has significant implications regarding safety.

### 5.2.2 UAS Sighting Reports and Database

A review of UAS sighting reports indicated that the amount and detail of information provided varied significantly. Generally, sighting reports from commercial pilots were more detailed, which may reflect the following considerations:

- Commercial pilots are more familiar with other safety reporting systems, such as wildlife strike reporting, runway incursion reporting, and the FAA's other aviation safety reporting programs.
- Commercial pilots are well-trained in reporting aviation safety events through professional and airlines' training.
- Commercial pilots may be required to provide this information to their airline.

Since the value of the UAS sighting database is enhanced by detailed and complete information, it is recommended that the FAA provide online resources regarding the submission of UAS sighting reports. This would include additional information for pilots, airport operators, air traffic controllers, and other parties, and would help improve completeness and accuracy of the

UAS sighting reports. In the online resources, FAA could provide examples of the kind of information that should be included for a complete UAS sighting report.

One recommendation of this research is for the development of an online reporting system for UAS sightings; this would be analogous to the online wildlife strike reporting system, and would eliminate the requirement that reports are filed through the FSDO. The widespread reporting of wildlife strikes by pilots, airport personnel, and air traffic controllers through the FAA Wildlife Strike Database has resulted in very comprehensive and detailed data that is widely used by airport operators, researchers, FAA, and the U.S. Department of Agriculture.

An online reporting system for UAS sightings could support increased details by providing a separate field for each key data component, such as UAS altitude, proximity to the closest airport, airport code, type of manned aircraft, proximity to manned aircraft, position of UAS relative to manned aircraft, and if evasive action is taken. With enhanced details, UAS sighting reports will become increasingly useful and as the database is used more frequently, awareness will increase in the aviation community. A more robust database will support additional research regarding airport safety and UAS sightings on and near airports.

An online UAS sighting reporting system would be expected to increase the records in the UAS sighting database. Other factors that may affect the number of UAS sighting reports in the future include:

- Increasing numbers of UAS: FAA (2020h) expected that there will be 1.59 million registered sUAS in the U.S. by 2024.
- Increasing aircraft movements: FAA (2020h) forecasted (before COVID-19) an average increasing rate of 0.9 percent a year at contract towers through 2040.
- Increasing awareness of the UAS sighting database: With outreach to airport operators and pilots, as well as law enforcement agencies and first responders (FAA, 2018d), the aviation and public safety community will be more familiar with the reporting protocol for UAS sightings.
- The requirement for remote identification for UAS: FAA (2020i) has been developing remote identification for UAS; this will ensure that in-flight UAS will provide identification information that can be received by other parties, such as aircraft pilots and air traffic controllers. This technology will assist the FAA, enforcement agencies, and federal security agencies, as well as support aircraft and airport safety.

### 5.2.3 UAS Sighting at Airports

In general, UAS sightings have not generally been a significant problem at U.S. airports to date, as demonstrated by the fact that there has only been one disruption to airport operations (the EWR case study), and that disruption was not significant. The EWR UAS sighting case demonstrated that a UAS sighting in the vicinity of an airport can have operational implications (aircraft delay, flights holding in the air, diverted flights, and flights briefly delayed before takeoff at other airports), but the operational impacts are consistent with impacts typically experienced due to weather and/or volume issues.

From an airport standpoint, it is important to understand the likelihood of a UAS sighting. Table 5.1 summarizes the likelihood of UAS sightings by characteristics based on analysis of the UAS sightings. As shown in Table 5.1, large hub and medium hub airports are more likely to be affected by UAS sightings. Since these airports have more scheduled air carrier operations that would be disrupted by a UAS sighting, it is recommended that these airports should be prepared to take action in the event of a future UAS sighting. Airports in densely populated urban areas and in states with large populations should also be prepared to respond to a UAS sighting.

Table 5.1 Likelihood of UAS sightings by characteristics.

| **Characteristics of UAS Sightings** | **Likelihood** | | |
|---|---|---|---|
| | **Low** | **Medium** | **High** |
| Airport category | Non-hub, commercial service, and GA airports | Small hub and reliever airports | Large hub and medium hub airports |
| Airport location | Rural area | Suburban area | Urban area |
| Month | January, February, November, December | March, April, September, October | May, June, July, August |
| State population | Less than 0.5 percent of the U.S. population | Between 0.5 and two percent of the U.S. population | More than two percent of the U.S. population |
| Time of day | 12 a.m. – 9 a.m. and 9 p.m. - 12 a.m. | 9 a.m. – 11 a.m. and 6 p.m. – 9 p.m. | 11 a.m. – 6 p.m. |

## 5.3 Recommendations for Future Studies

This research has found a variety of valuable information that is related to UAS. There is a significant need for additional related research. This research developed a binary logistic regression model to explain the relationship between the need for an evasive action due to a UAS sighting and the time of day, type of operation, and position of UAS relative to manned aircraft. Future research could investigate other factors that may affect the need for evasive action, as well as factors that may affect the likelihood of a UAS sighting near an airport. A multinomial logistic regression model can be applied to study the relationships between airport category (the dependent variable) and the characteristics of UAS sightings (independent variables), including time of day, altitude of UAS, proximity to airport, airport location, airport operations, manned aircraft type, proximity to manned aircraft, notification to law enforcement, issuance of MOR, and evasive action.

The EWR UAS sighting illustrated the impact of a relatively short disruption to flight operations due to a UAS sighting. A longer disruption to aircraft operations due to a UAS sighting may results in more and different airport impacts, and impacts that may propagate through the airport system. Future research can focus on the impact of a longer disruption to operations due to a UAS sighting (lasting for many hours); it may be appropriate to utilize advanced mathematical models calibrated with data based on weather and volume delays for this research.

The interviews with airport operators provided a useful perspective on UAS. Additional interviews and surveys with additional airport personnel from different airports would be helpful. To better understand the perspective of airport operators regarding UAS, it would be helpful to interview airport personnel from airports of different sizes and categories, in a wide variety of different regions and states.

## 5.4 Summary

UAS is an increasingly important participant in aviation and since safety is the top priority for the aviation industry, it is imperative to conduct research to ensure the safe integration of UAS with existing activities. This research provided insights on the characteristics of UAS sightings, impacts of UAS sightings on airport operations, and the perspective of airport personnel regarding the UAS at airports. Findings from this study may be used to guide future research and risk mitigation, which is recommended at large and medium hub airports, especially those in urban areas in highly populated states. This study demonstrates the value of UAS sighting reports, which facilitate a better understanding of characteristics and potential impacts on aviation safety, including airport operations. Given that the UAS industry is rapidly developing, a safe airport environment is critical. The findings of this research and the limited number of other studies in this area suggest that future research on UAS and airport safety is warranted and should be priority.

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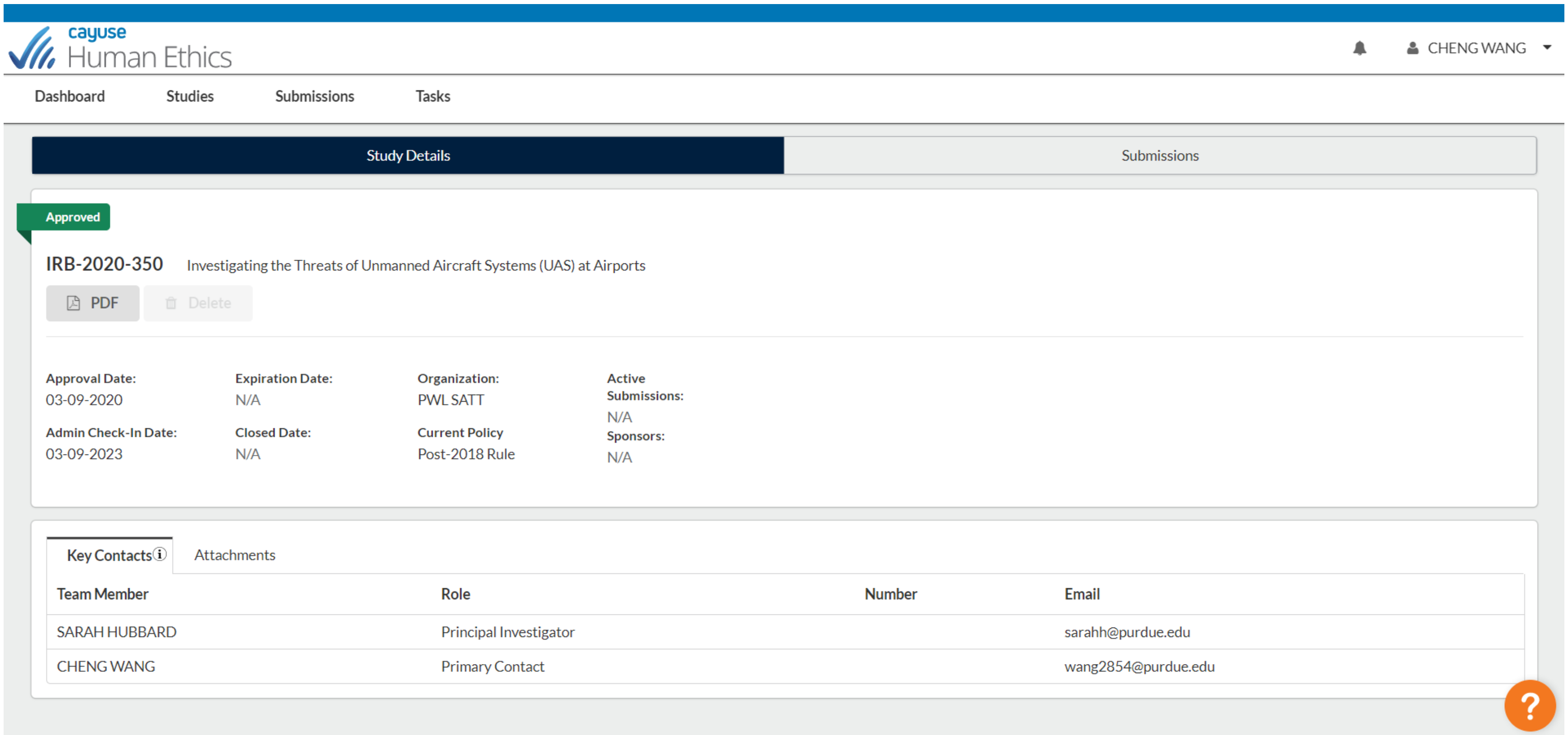
# APPENDIX A: SAMPLE UAS SIGHTING REPORT

| Event Date & Time | CITY | STATE | Event Description |
|---|---|---|---|
| 1-Sep-16 | WHITE PLAINS | New York | PRELIM INFO FROM FAA OPS: WHITE PLAINS, NY/UAS INCIDENT/1130E/NY TRACON REPORTED JET BLUE, E190, PBI - HPN, OBSERVED A UAS AT 2,000 FEET 5 SE HPN. NO EVASIVE ACTION REPORTED. LEOS NOT NOTIFIED.<br><br>UAS MOR Alert for N90<br>Type: Hazardous and/or Unauthorized UAS Activity<br>Date/Time: Sep 2, 2016 - 0330Z<br>A/C: (E190)<br>Summary: E190 REPORTED A DRONE WHILE ON APPH TO HPN. |

# APPENDIX B: INSTITUTIONAL REVIEW BOARD APPROVAL



cayuse Human Ethics

CHENG WANG

Dashboard Studies Submissions Tasks

Study Details | Submissions

Approved

IRB-2020-350 Investigating the Threats of Unmanned Aircraft Systems (UAS) at Airports

PDF Delete

Approval Date: 03-09-2020

Expiration Date: N/A

Organization: PWL SATT

Active Submissions: N/A

Admin Check-In Date: 03-09-2023

Closed Date: N/A

Current Policy Post-2018 Rule

Sponsors: N/A

Key Contacts Attachments

| Team Member | Role | Number | Email |
|---|---|---|---|
| SARAH HUBBARD | Principal Investigator | | sarahh@purdue.edu |
| CHENG WANG | Primary Contact | | wang2854@purdue.edu |

# APPENDIX C: RECRUITING EMAIL FOR INTERVIEW

Dear xxx,

My name is Vivian (Cheng) Wang and I am a researcher working with Prof. Sarah Hubbard in the School of Aviation & Transportation Technology at Purdue University. I am conducting my dissertation research which investigates UAS and airport safety. My research study titled "investigating the threats of unmanned aircraft systems (UAS) at airports." I am writing to ask if we can learn about your thoughts regarding the perceived threat of UAS at your airport by a brief interview. Your participation will be extremely valuable to the understanding of current perspective of airport personnel regarding the risk of UAS at airports.

This study has been approved by Purdue University Institutional Research Board. Your participation is completely voluntary and anonymous. We will compile information based on airport category. All information reported in our research will be anonymous.

If you are willing to participate please suggest a day and time that suits you. If you have any questions, comments, or concerns about this research project, please do not hesitate to contact me at wang2854@purdue.edu. Thank you very much for your time and for sharing your perspective to support our research on this important topic.

Sincerely,

Vivian (Cheng) Wang<br>
Ph.D. Candidate<br>
School of Aviation & Transportation Technology, Purdue University<br>
E-mail: wang2854@purdue.edu

# APPENDIX D: INTERVIEW QUESTIONS

Q1 Have you had a UAS sighting at or in the vicinity of your airport? *(Yes/No)*

Q1.1 If your airport has had a UAS sighting, could you please describe the event?

Q2 Has your airport deployed airport police or contacted local police regarding UAS in the vicinity of the airport in response to a UAS sighting? *(Yes/No)*

Q2.1 If yes, were airport police, city police, or the county sheriff deployed? Did they find the drone and/or operator?

Q2.2 If yes, how many times have you deployed airport police or contacted police?

Q3 Has your airport recovered any drones on airport property? If yes, how many drones has your airport recovered (over what time period)?

Q4 Have you heard of the FAA's UAS Sightings Report datasets? *(Yes/No)*

Q4.1 If yes, have you looked at or filed a report with the UAS Sighting database?

Q5 Have you heard of the FAA's Wildlife Strike Database? *(Yes/No)*

Q5.1 If yes, have you looked at or filed a report with the Wildlife Strike database?

Will show participants the UAS Sighting Database and Wildlife Strike Database if they would like to see the websites.

Q6 Have you included UAS surveillance in your training, inspection, or safety bulletins or airport communications activities?
*Potential answer: A. Currently include*
*B. Plan to include*
*C. No plans to include*

Q7 Have you included wildlife surveillance in your training, inspection, or safety bulletins or airport communications activities?
*Potential answer: A. Currently include*

*B. Plan to include*
*C. No plans to include*

Q8 Have you investigated drone detection technologies for your airport?
*Potential answer: A. No*
*B. No, but we are interested*
*C. Yes, we have read about it*
*D. Yes, we have spoken to vendors*

Q9 Does your airport have a Tactical Response Plan for UAS sightings?
*Potential answer: A. Yes*
*B. No, but we are developing the plan*
*C. No, but I would like to learn more about it*
*D. No, it is not necessary at our airport*

Q10 How effective do you think your AEP is for a drone sighting and or drone strike?
*Not effective at all Somewhat effective Effective Very effective*

Q11 What is the overall threat due to UAS at your airport?
*Very low Low Neutral High Very High*

Q12 What is the overall threat due to wildlife at your airport?
*Very low Low Neutral High Very High*

Q13 Some airports have used UAS to support airport operations. Are you interested in using UAS for airfield inspections in the next year or two?
*Potential answers: A. Not at all interested*
*B. Not very interested*
*C. Neutral*
*D. Moderately interested*
*E. Very interested*

Q13.1 If the participant expresses interest in Q13, what kind of inspections would you be interested in using UAS to support?

| | We have done this | Interested in this | Not interested in this |
|---|---|---|---|
| Pavement inspections | | | |
| Perimeter inspections | | | |
| Other, please describe | | | |

Q14 Would you like to share any other comments about your experience or thoughts regarding UAS and your airport?

Q15 Would you like us to include your airport code in our data record and/or our acknowledgements? *(Yes/No)*

Q16 Would you like us to include your name in our acknowledgements? *(Yes/No)*

We will potentially follow up with other related questions, as appropriate, depending on the responses since this is a semi-structured interview. All questions will focus on UAS and airport safety rather than personal data.

# APPENDIX E: INTERVIEW NOTES

## Airport A
## Interview date: June 17, 2017

- Airport A is a Part 139 and regional GA airport
- Question 1
  - Answer: have not had a UAS sighting at or in the vicinity of the airport
  - The airport manager was not notified of any UAS sighting
  - One report in the FAA's UAS sighting database
  - Question 1.1 – airport operations, maintenance, ATC may be involved when a UAS sighting occurs
- Question 2
  - Answer: have not deployed airport police or contracted local police regarding UAS in the vicinity of the airport
  - Question 2.1and question 2.2 - blank
- Question 3
  - Answer: have not recovered any UAS on airport property
- Question 4
  - Answer: did not heard of the FAA's UAS sighting database
  - Question 4.1 - blank
- Question 5
  - Answer: yes, know about the wildlife strike database and have used it
  - Question 5.1 – yes, fill reports, read reports in the database, or notified by the FAA
- Question 6
  - Answer: no plans to include UAS surveillance in training, inspection, safety bulletins, or airport communication activities
- Question 7
  - Answer: no plans to include wildlife surveillance in training, inspection, safety bulletins, or airport communication activities
- Question 8
  - Answer: no, have not investigated UAS detection technologies
  - From December 2019 to January 2020, the FAA's airport certificate inspectors contacted all Part 139 airports, but the FAA have not approved anything yet
  - No formal communication from the FAA
  - Some airports have already started investigating UAS detection technologies
- Question 9
  - Answer: no tactical response plan for UAS sightings
- Question 10
  - Answer: the airport has an AEP
- Question 11
  - Answer: overall threat due to UAS is neutral, not sure (does not know a lot)
  - No report so far, but it can be there
- Question 12

- Answer: overall threat due to wildlife is neutral
- There are birds, deer, fox, etc.
- Wildlife is a threat to the airport, but it can be mitigated, with the use of technologies
- Both UAS and wildlife are potential threats to the airport

- Question 13
  - Answer: very interested in using UAS for airfield inspections
- Question 13.1
  - Not necessary for day to day pavement and perimeter inspections
  - Somewhat interested in using UAS for pavement inspections
  - Very interested in using UAS for perimeter inspections
    - Might be valuable
    - Can be used to conduct inspections every one to two weeks
    - Perimeter inspections can't be conducted when there is flooding
    - During winter, airports can't have perimeter inspections in heavy snow (150 inch)
  - Other applications of UAS
    - Valuable for lighting inspections, building/roof leaking/facility inspections, visual inspections off airport properties (e.g. cranes, trees)
    - To check PAPI
      - Using aircraft/helicopter to check is very subjective (FAA do so) and expensive (cost $10k); can save money by using UAS (a UAS with a camera is about $1000)
      - Can do the inspection more often
      - To test ILS equipment
      - UAS have more capabilities (can be stopped, stay stationary, real time, adjust angels)
- Question 14
  - Using infrared to find animals' ground nests
    - Some animals like to have ground nests
    - For a 525-acre area, to find an animal's nest is similar to looking for a needle in a haystack
    - Can use handheld cameras to find nests
    - Even bigger UAS are hard to see from a long distance
- Question 15: yes
- Question 16: yes
- Additional questions: what will you do if you see a UAS (the protocol of a UAS sighting)
  - Determine if it is significant or not to aircraft, or if it presents threats to aircraft
  - Drive to the area to find the operator if can be found
  - Call airport air traffic control tower, shutdown runways if needed
  - Call police department (hand to law enforcement agency)
    - They may ask what they are going to do
    - May fine the operator
    - If the UAS is on runway, they don't know what to do
    - Don't have handy local laws that tells them how to deal with it

**Airport B**
**Interview date: June 25, 2020**

- Airport B is a Part 139 and non-hub airport
- Different responses to different situations (depending on the situation: terrorism or not)
- Question 1
  - Answer: have not seen UAS sightings in the air near the airport, no issue with UAS sightings
  - Four reports in the FAA's UAS sighting database
  - Question 1.1
    - One incident occurred, found a UAS on the landside, laying on the ground, next to fence and loading dock
    - Called the airport traffic control tower to let them know that the UAS was sitting on the ground and asked if ATC had seen anything
    - Used cameras in the vicinity of that area to know about the situation
    - A truck was parking next to the fence and the UAS was sitting in the truck and had not been flown
    - Contacted county sheriff and let them to start the investigation, and told police officers what had been found through the camera and the license plate of the truck
    - The event did not cause big influences
    - The airport has UAS sighting procedures for the airport/ATC to go through when they see something
- Question 2, question 2.1, question 2.2, and question 3
  - Process with TSA in fall 2019
    - Operations, maintenance, rescue and firefighting, and airport security were involved
    - Had conversation with county sheriff and FBI about if something happens
    - For a regular UAS sighting: when the UAS appears in the flight path, the airport air traffic control tower will stop air traffic for a short amount of time; the law enforcement agency will be dispatched to look into further; the operator may be educated about the operation rules
    - For a targeted approach: the event will be led by FBI and TSA, and TSA may has heard of it or may know if the airport is a part of a larger scare attack; the airport will support FBI and TSA, and the airport doesn't have authority to shoot down or to take any approaches and doesn't have anything locally to stop the activity (military does have)
    - The airport is very low on the level of a coordinated attack (agreed with FBI and TSA), and may not affect the national air transportation system
    - Attacks are more likely to occur at large hub airports since they will disrupt more air travels and cause more national scare
  - Conversations with Local Emergency Management Association (EMA) before fall 2019
    - EMA has been using UAS for body/people searching for five years
    - Had UAS before rules (maybe Part 107) came out
    - The community has aware of UAS technologies
- Question 4
  - Answer: did not heard of the FAA's UAS sighting database
  - Q4.1 - blank

- Question 5 and question 5.1
  - Answer: know about the wildlife strike database well
  - The airport uses a computer program to track all emergency responses, incident reports, etc.
  - Balance between comprehensive and concise for information in the program
- Question 6
  - Have not spent specific time on training for UAS surveillance
  - There is a section of “other items” (like cranes) in daily airfield training
  - UAS may in the same category as cranes
  - Inspectors who do daily airfield inspections are aware of UAS
  - Maintenance personnel also go through Part 139 training, to make sure maintenance personnel know what they are looking for when they are on the airfield; so maintenance personal would report it and go through the procedures if they see something
- Question 7
  - Answer: currently include wildlife training (had trainings in the last three years)
  - USDA used to handle all wildlife trainings, but consultants perform trainings now
- Question 8
  - Answer: have not investigated UAS detection technologies
  - Current status: UAS detection technologies are not AIP eligible
  - Top 50-100 airports may immediately request it when it is AIP eligible
  - Also, the airport’s operation budget is $8M, but the input on UAS detection technologies may cost $80k - $150k
  - TSA: giving its own grant funding to systems, cameras, access control, and security checkpoint
- Question 9
  - Answer: do not have a tactical plan for UAS sightings, but should have something more formalized
  - If a UAS is spotted, it will be reported to the airport air traffic control tower and authorities; local law enforcement agency will involve in the event, since the airport does not have airport police department that can investigate; the airport will start shutting things down properly (e.g. land aircraft on the other side of the airport) if the UAS poses an immediate threat
  - The airport does not make the decision; pilots and ATC make the decision together
- Question 11
  - Answer: overall threat due to targeted threats is very low; overall threat due to random UAS sightings is low to neutral
  - The helipad at the top of the hospital (near the airport) is in a higher danger level because of amateurs
- Question 12
  - Answer: overall threat due to wildlife strikes is neutral
  - The airport did good jobs in wildlife management but still have wildlife strikes
  - Passed the spring season, more in the fall season, very low in summer
- Question 13 and question 13.1
  - Answer: will use it in some point
  - In 5-15 years, engineers will video edges of pavements, or the airport will use UAS to do visual inspections

    - Current step: waiting for the integration of UAS into the ATC system, and waiting till the airport has a budget
    - Heat map function for creeks
- Question 15: yes
- Question 16: yes

**Airport C**
**Interview date: June 30, 2020**

- Airport C is a regional GA airport, not a Part 139 airport
- Question 1
    - Answer: yes & no
    - Had coordinated operations in the airport airspace
    - Had operations for agriculture or photography purpose
    - All operations were being notified in advance
    - No report in the FAA's UAS sighting database
- Question 2
    - Answer: have not deployed police department or local police department for UAS sightings in the vicinity of the airport
    - Reached out to law enforcement agencies, including county sheriff and local police department, and advised them the FAA's information
    - The legal contact is the county sheriff department; the local police department is under contract with the airport and comes to the airport at least once a day
    - Question 2.1 and Question 2.2 - blank
- Question 3
    - Answer: have not recovered any UAS on airport property
- Question 4
    - Answer: did not heard of the FAA's UAS sighting database
    - Q4.1 - blank
- Question 5
    - Answer: heard of the FAA's wildlife strike database
    - Question 5.1 - used the database
- Question 6
    - Answer: no plans to include UAS surveillance in training, inspection, safety bulletins, or airport communication activities
    - Informal communications, do not have SOP developed
    - Have not created or formalized a UAS training program
    - The airport has two full-time employees and a variety of part-time employees
- Question 7
    - Answer: do not have protocol for wildlife training, but do have wildlife inspections
    - Wildlife is different from UAS at the airport, since there have been wildlife strikes
    - Advise airport air traffic control tower when there are birds in the sky
- Question 8
    - Answer: have minorly investigated UAS detection technologies
    - Interested in seeing how UAS can cooperate with the airport
    - Pay attention to briefings and presentations at the Aviation Indiana Conference and TRB's reports

- Question 9
  - Answer: no tactical response plan for UAS sightings
  - Interested in seeing plans for other GA airports in similar size
- Question 10
  - Answer: AEP is somewhat effective for UAS sightings or UAS strikes (some parts of the AEP can be applied to UAS sightings)
  - FAA is the #1 contact
- Question 11
  - Answer: overall threat due to UAS is low
  - Location of the airport: rural agriculture area, not a high populated area
  - Size of UAS: three to four feet wide
- Question 12
  - Answer: overall threat due to wildlife is neutral to high, depends on the time of the year
  - Bird issues and deer issues
  - Try to mitigate
- Question 13
  - Answer: very interested in using UAS to support airfield operations
- Question 13.1
  - Answer: interested in using UAS for both pavement and perimeter inspections
    - Frequency of pavement inspection: daily
    - Frequency of perimeter inspection: once a month
  - Other application: using UAS for photographing construction projects, and keep updating the progress
- Question 14
  - As technology develops, UAS will be a great platform, which can save time and money (e.g. scanning & photography)
- Question 15: yes
- Question 16: yes
- Additional question: what would the airport do if a UAS is spotted?
  - Go to the FAA's website and find the owner of the UAS
  - Reach out to FSDO and Airport District Office
  - May involve law enforcement agencies

**Airport D**
**Interview date: September 15, 2020**

- Airport E is a Part 139 and medium hub airport
- The airport authority operates six airports in the metropolitan area, including one medium hub airport, four reliever airports, and one heliport
- Question 1
  - Answer: have not had UAS sightings at or in the vicinity of the airport
  - Other reliever airports had UAS sightings previously, but no UAS sighting occurred recently
  - One UAS sighting was reported by a pilot at a reliever airport, and one UAS sighting occurred at another reliever airport
  - Q1.1 – blank
  - 11 reports in the FAA's UAS sighting database

- Question 2
  - The Alert Warning System (AWS) group at the airport is responsible for UAS sightings. It involves several agencies in and around the metropolitan area, including TSA, FAA, FBI, ATF, U.S. CBP, and local police department. When a UAS is spotted around the airport, the airport will call the AWS. The TSA officer in the AWS group will notify everyone in this group. The group and the airport will try to locate the UAS and the operator, and try to get the UAS out of the air as soon as possible.
  - The AWS group did not exist when UAS sightings occurred at other airports.
  - Question 2.1 and question 2.2 - blank
- Question 3
  - Answer: have recovered two UAS on airport property
  - 1st UAS: Spotted by an airport operations manager at night, and the UAS was landed on the airport property. The airport operations notified the airport traffic control tower. The airport notified FSDO. FSDO came to the airport, confiscated the UAS, and conducted the investigation. It was found that the UAS was flown by an individual on the east side of the airport. The individual did not know about the rules of flying UAS around airports and lost sight of the UAS. FSDO found the owner of the UAS.
  - 2nd UAS: airfield maintenance department was mowing grass and found the UAS in the grass. The UAS was run over by a tractor, so there is no information about how the UAS got there. The airport contacted FSDO. FSDO came to the airport and took the UAS.
- Question 4
  - Answer: have heard of the FAA's UAS sighting database
  - Question 4.1 – have not used it
- Question 5
  - Answer: have heard of the FAA's wildlife strike database
  - Question 5.1
    - Use the database quite a bit, and wildlife strikes are reported through the database
    - Have a full-time wildlife biologist at the airport
- Question 6
  - Answer: currently include UAS surveillance in training
  - Airport operations managers receive the training that explains the AWS group, to make sure that airport operations managers are aware of the group
- Question 7
  - Answer: currently include wildlife surveillance in training
  - The wildlife biologist performs annual recurrence training for all staffs
- Question 8
  - Answer: have spoken to a local company about UAS detection technologies
  - The company works on developing ways to identify UAS that shows up unannounced
  - The airport is early in the process and trying to find out what is available and what works
- Question 9
  - Answer: have a tactical response plan for UAS sightings
  - The AWS group is a part of the tactical response plan. When a UAS sighting occurs, the airport operations department will respond to the area and contact airport air traffic control tower to see what type of issue the UAS is causing at the airport. The airport will notify airlines, since flight schedules may be disrupted temporarily. The airport may deliver message through social media if the UAS sighting will be extended. The airport

public affairs department will notify local new media. The local police department may use their UAS to look for the operator.

- Question 10
    - Answer: the tactical response plan works (rating between effective and very effective)
    - Once the airport receives the notification of the UAS sighting in the vicinity of the airport, the airport has a good plan to move forward
    - Always try to improve the plan and get better
- Question 11
    - Answer: overall threat due to UAS sightings is very low
    - Low frequency and high impact events
- Question 12
    - Answer: overall threat due to wildlife strikes is low
    - Because the airport has a full-time USDA biologist advises the airport on ways to mitigate wildlife strikes, such as height of grass, how often to mow, type of grass that is unattractive to wildlife, and looking for attractive things at the airport
- Question 13
    - Answer: moderately interested in using UAS to support airport operations
    - Not sure how UAS can be used effectively for now
- Question 13.1
    - Answer: UAS can be used for pavement inspections, perimeter inspections, and wildlife management to spot flocks of birds and mammals at airports
- Question 14
    - The airport used to have issues with people shining lasers
- Question 15: yes
- Question 16: yes
- Additional question: about the UAS activity form online
    - It is quite often to receive UAS activity requests from commercial operators for photography purpose

**Airport E**
**Interview date: July 3, 2020**

- Airport D is a Part 139 and small hub airport
- Question 1
    - Answer: have had one reported UAS sighting
    - Question 1.1
        - 4.9 miles away from the airport
        - Reported by a member of the community who lives nearby; the person told the airport that they should be aware of it
        - The airport did not see the UAS
    - Five reports in the FAA’s UAS sighting database
- Question 2
    - Answer: have not deployed airport police or contacted local police regarding UAS sighting in the vicinity of the airport
    - Question 2.1 and question 2.2 - blank
- Question 3
    - Answer: have not recovered any UAS on airport property

- Question 4
  - Answer: have not heard of the FAA’s UAS sighting database
  - Question 4.1 - blank
- Question 5
  - Answer: haven heard of the FAA’s wildlife strike database
  - Question 5.1- have seen reports and trained to use it, but have not filled a report
- Question 6
  - Answer: no training, inspection, safety bulletins, or airport communication activities for UAS surveillance
- Question 7
  - Answer: have wildlife training
  - A wildlife biologist performs training for all operations and maintenance personnel annually
  - Training contents: bird identification, how to file a wildlife strike report, what have been reported in the past year, etc.
- Question 8
  - Answer: have not investigated UAS detection technologies
- Question 9
  - Answer: no tactical response plan for UAS sightings at the airport
- Question 10
  - Answer: the AEP is somewhat effective for UAS sightings or UAS strikes
  - AEP hands emergency in general
  - Perhaps the AEP for wildlife strikes can be applied to UAS sightings
- Question 11
  - Answer: overall threat due to UAS is low
- Question 12
  - Answer: overall threat due to wildlife is neutral
  - The airport conducts daily check for wildlife
  - More wildlife strikes than UAS issues at the airport
- Question 13
  - Answer: moderately interested in using UAS for airfield inspections
- Question 13.1
  - Answer: interested in both pavement and perimeter inspections
  - Other application of UAS: lightning inspections
- Question 15: no
- Question 16: no
- Additional question: what the airport will do if someone see a UAS at or in the vicinity of the airport
  - Contact airport air traffic control tower and follow the feedback given by ATC (ATC will tell the airport what to do), may contact the police department
  - The interviewer was being told to contact ATC and take directions from them when there is a UAS sighting report

# VITA


## Cheng Wang

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### EDUCATION

**Ph.D.** in Aviation Technology 08/2017-12/2020
Purdue University, School of Aviation and Transportation Technology West Lafayette, IN

**M.S.** in Aviation and Aerospace Management 08/2015-05/2017
Purdue University, School of Aviation and Transportation Technology West Lafayette, IN

**B.E** in Safety Engineering 09/2011- 06/2015
Civil Aviation University of China, College of Safety Science and Engineering Tianjin, CN

### WORK EXPERIENCE

**Statistical Data Analysis Intern** 07/2019-12/2019
International Civil Aviation Organization (ICAO) Montreal, QC
*Responsibilities:* Air transport data collection, verification, and analysis; development and improvement of electronic tools for data verification; conducting research on airlines, airports, civil aviation authorities, and relevant bodies to fill out the data gaps.

**Human Factors Research Intern** 05/2018-08/2018
Federal Aviation Administration William J. Hughes Technical Center Atlantic City, NJ
*Responsibilities:* Conducting a pilot study on air traffic controllers' workload and performance, and measurement of eye movements and brain activities; generating research reports; setting up protocols for the full-scale research project to support predictions of air traffic controllers' workload and performance in long-term.

**Safety and Quality Management Intern** 07/2014-09/2014
Shanghai Hawker Pacific Business Aviation Service Center Shanghai, CN
*Responsibilities:* Accident and incident reporting system management; safety document management; safety training management; assisting internal audit.

## TEACHING EXPERIENCE

**Instructor,** Purdue University Spring 2020-Fall 2020
*Course:* Aviation Business West Lafayette, IN
*Responsibilities:* Developed and delivered three-hour weekly lectures on aviation business to 90 undergraduate students in aviation majors; designed and graded homework assignments, weekly quizzes, and exams; held office hours.

**Teaching Assistant,** Purdue University Fall 2018-Spring 2019
*Course:* Introduction to Aviation Technology West Lafayette, IN
*Responsibilities:* Developed and delivered lectures on basic aviation knowledge to over 200 freshmen in aviation majors; graded weekly assignments; critiqued student papers and provided feedback to students; proctored and graded exams.

**Teaching Assistant,** Purdue University Spring 2019
*Course:* Aviation Law West Lafayette, IN
*Responsibilities:* Prepared and conducted monthly discussions on aviation laws and regulations with undergraduates; led and facilitated student discussions on case studies with focuses on specific aviation laws; assisted students in group projects; proctored exams.

**Teaching Assistant,** Purdue University Fall 2018
*Course:* Airport Operation West Lafayette, IN
*Responsibilities:* Developed and delivered lectures on airport operations to juniors majoring in Aviation Management; assisted students in individual and group projects; organized field trips to the local airport and led airport tours.

**Guest Speaker,** Purdue University Fall 2017
*Course:* Research Methods West Lafayette, IN
*Responsibilities:* Invited to teach one lecture on my research to graduate students; delivered a 75-minute lecture on doing a literature review and systematic literature review to 20 graduate students in the School of Aviation and Transportation Technology.

## RESEARCH EXPERIENCE

**Graduate Researcher,** Purdue University 08/2017-Present
*Advisor:* Sarah Hubbard
*Dissertation Thesis:* Investigating the Threats of Unmanned Aircraft Systems (UAS) at Airports
*Topics:* Comparisons among airport hazards
Understanding characteristics of unmanned aircraft systems (UAS) sightings in the U.S.
Identification and analysis of primary and secondary runway incursions in the U.S.
Identification and synthesis of contributing factors of runway incursions
Issues encountered by international students during flight training in the U.S.

**Graduate Researcher,** Purdue University 08/2015-05/2017
*Advisor:* John Young
*Topic:* Sources of psychological stress on student pilots during flight training

**Undergraduate Researcher,** Civil Aviation University of China 02/2015-06/2015
*Advisor:* Yanqing Wang
*Topic:* Air traffic controllers' unsafe actions analysis based on cognitive theory

## REFEREED PUBLICATIONS

Lu, C., **Wang, C.**, & Jin, L. (2020). Qingdao airlines emergency management system analysis: A case study in handling suspected fuel leakage event by flight crews. *International Journal of Crisis Management, 10*, 29-36.

**Wang, C.**, Hubbard, S. M., & Zakharov, W. (2018). Using the systematic literature review in aviation: A case study for runway incursions. *Collegiate Aviation Review International, 36*(2), 33-35. doi: http://dx.doi.org/10.22488/okstate.18.100489

## NON-REFEREED PUBLICATIONS

**Wang, C.,** Hubbard, S. M., Zakharov, W. (2019, June). *Utilizing the systematic literature review in aviation: A case study for runway incursions.* Poster presented at 2019 Special Libraries Association Conference, Cleveland, OH.

**Wang, C.,** Hubbard, S. M., Zakharov, W. (2018, October). *Utilizing the systematic literature review in aviation: A case study for runway incursions.* Paper presented at the Collegiate Aviation Conference & Expo, Dallas, TX.

Hubbard, S. M., & **Wang, C.** (2018, April). *An examination of issues encountered by international students during flight training in the U.S.* Poster presented at the American Society of Engineering Education (ASEE) Illinois-Indiana Section, West Lafayette, IN.

**Wang, C.**, Hubbard, S. M., & Zakharov, W. (2018, March). *Utilizing the systematic literature review in aviation: A case study for runway incursions.* Poster presented at the Purdue Road School Transportation Conference & Expo, West Lafayette, IN.

**Wang, C.**, Zorrilla, M., Sanchez, G., & Hubbard, S. M. (2017, March). *Issues with international flight training in the U.S.* Poster presented at the Institute of Transportation Engineers Indiana Purdue Student Chapter, West Lafayette, IN.

**Wang, C.**, Zorrilla, M., Sanchez, G., & Hubbard, S. M. (2016, November). *Issues with international flight training in the U.S*. Poster presented at the Institute of Transportation Engineers Indiana Purdue Student Chapter, West Lafayette, IN.

## PUBLICATIONS IN PROGRESS

**Wang, C.,** & Hubbard, S.M. (2020). *Characteristics of unmanned aircraft systems (UAS) sightings.* Manuscript in progress.

**Wang, C.,** & Hubbard, S.M. (2020). *Comparing airport hazards: unmanned aircraft systems (UAS) sightings, wildlife strikes, and runway incursions.* Manuscript in progress.

**Wang, C.,** Deng, S., & Hubbard, S.M. (2020). *Identification and statistical analysis of primary and secondary runway incursions in the U.S.* Manuscript in progress.

## COLLABORATIVE PROJECTS

**Qingdao Airlines** & Purdue University 08/2018-12/2018
*Project:* Establishment and Development of Family Assistant Operation Plan Qingdao, CN

**Purdue Aviation** & Purdue University 08/2016-12/2016
*Project:* Renovation and Optimization of Flight Operation Center West Lafayette, IN

**United Ground Express** & Purdue University 01/2016-05/2016
*Project:* Airport Manpower Resource Management and Equipment Management Chicago, IL

**Republic Airways** & Purdue University 10/2015-12/2015
*Project:* Advanced Qualification Program Assessment and Improvement Indianapolis, IN

**Republic Airways** & Purdue University 08/2015-10/2015
*Project:* Aviation Safety Action Program Optimization Indianapolis, IN

## HONORS & AWARDS

**Civil Aviation Safety Management Case Study Contest Second Place** 12/2018
*Subject:* Qingdao Airlines SMS Analysis: A Case Study of Suspected Aircraft Fuel Leakage Event

**Swengel Graduate Student Scholarship** 04/2018
Purdue University, School of Aviation and Transportation Technology

**PEGASAS Fellowship** 02/2018
Federal Aviation Administration Centers of Excellence

**University Aviation Association Poster Contest Graduate Category First Place** 09/2017
*Subject:* Sources of Psychological Stress on Student Pilots during Flight Training

**Ross Fellowship** 04/2017
Purdue University, Polytechnic Institute

## PROFESSIONAL AFFILIATIONS

University Aviation Association, Student Member 04/2020-Present

American Association of Airport Executives, Academic Graduate Member 08/2016-Present

Women in Aviation International, Student Member 08/2016-Present

## CERTIFICATION

Federal Aviation Administration **Remote Pilot** Certification 01/2019

Federal Aviation Administration **Aircraft Dispatcher** Certification 08/2018

**SAS Base Programming** for SAS 9 11/2016