The FAA's Center of Excellence for UAS Research
ASSURE
Alliance for System Safety of UAS through Research Excellence

Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic Trends and Safety: Supplement A - Phase 1

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16. Abstract

The Federal Aviation Administration (FAA) tasked its Center of Excellence (COE) for Unmanned Aircraft Systems (UAS), ASSURE (Alliance for System Safety of UAS through Research Excellence), to conduct research to inform the safe integration of sUAS (small UAS) for expanded (e.g., beyond-visual-line-of-sight) and non-segregated UAS operations. The objectives of this research focus on the evaluation of data, projection of demand for UAS operations, and development of a risk-based framework for an SMS (Safety Management System) process that incorporates Probability Risk Assessments (PRAs). Task 1-1 of this project supports the goals by evaluating historical data provided collected by the FAA to develop a data catalog for UAS integration-relevant data analysis. Task 1-2 surveys and describes UAS Concepts of Operations (CONOPS) with a focus on sUAS (small UAS). The CONOPS can be organized according to high-level as: BVLOS (Beyond Visual Line of Sight); Operations over People; and Operations over Moving Vehicles. Across these three categories, UAS approval letters were analyzed. Task 1-3 quantitative analysis on data catalogued in Task 1-1 to identify trends, perform qualitative analysis of SMS versus current and proposed Part 107 waivers, and summarizes observed gaps in current data sets and data collection practices impacting the ability to describe, interpret, and predict the impact of rulemaking on UAS integration. Task 1-4 validates the database of visual sighting reports. Utilizing UAS detection and tracking data and manned flight tracks, researchers assess UAS operator adherence to Part 107 rules, the characteristics of sUAS operations in the vicinity of airports, and the comparison of sighting report data with observations from the drone detection data

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Table of Acronyms

Acronym	Meaning
ADS-B	Automatic Dependent Surveillance-Broadcast
AI	Artificial Intelligence
ANPRM	Advanced Notice of Proposed Rulemaking
ARIMA	Auto Regressive Integrated Moving Average
ASIAS	Aviation Safety Information Analysis and Sharing
ASSURE	Alliance for System Safety of UAS through Research Excellence
AUVSI	Association for Unmanned Vehicles System International
AWS	Amazon Web Services
BCT	Brigade Combat Team
BVLOS	Beyond Visual Line Of Sight
C2	Command and Control
CAD	Computer-Aided Design
CFR	Code of Federal Regulations
COE	Center Of Excellence
CONOPS	CONcept of OPerationS
DAA	Detect And Avoid
DTI	Danish Technological Institute
E/O	Electro/Optical
EO/IR	ElectroOptical/InfraRed
ERAU	Embry-Riddle Aeronautical University
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FedBizOpps	Federal Business Opportunity
GPS	Global Positioning System
GSM	Global System for Mobile communications
HD	High Definition
IPP	Integration Pilot Program
IR	InfraRed
ISR	Intelligence, Surveillance, and Reconnaissance
LAANC	Low Altitude Authorization and Notification Capability
LiDAR	Light Detection And Ranging
LOS	Line of Sight
MAAP	Mid-Atlantic Aviation Partnership
MLS	Mission Logging System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NMSU	New Mexico State University
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NPRM	Notice of Proposed Rulemaking
NTAS	National Training Aircraft Symposium
PMERJ	Military Police of Rio de Janeiro State
PPK	Post Processing Kinematic
PRA	Probabilistic Risk Assessment
QA	Quality Assurance
RF	Radio Frequency
RFI	Request For Information
SMS	Safety Management System
SRM	Safety Risk Management
sUAS	small UAS
TAAC	Technical Analysis and Applications Center
TFMS	Traffic Flow Management System

UA	Unmanned Aircraft
UAE	United Arab Emirates
UAF	University of Alaska Fairbanks
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UTM	Unmanned Traffic Management
VIO	Visual Inertial Odometry
VO	Visual Observer
VTOL	Vertical TakeOff and Landing
WAG	Waiver Application Guidelines

Executive Summary

The Federal Aviation Administration (FAA) seeks to gain insights, lessons learned, and recommendations for future data collection practice based on analysis from the data sets it has generated over the past half-decade of unmanned aircraft system (UAS) integration programs. Data sets (2015-2020) include UAS registrations, remote pilot examinations and certificates issued, flight waivers issued, sighting reports, and operational data. An ASSURE Center of Excellence (COE) team from Embry-Riddle Aeronautical University, the University of North Dakota, and Kansas State University-Salina report their analysis findings to inform future data collection and analysis practices and to support the development of a probability risk assessment (PRA) framework to guide future UAS rulemaking and risk-based operational assessment.

Understanding current data collection practices. This effort seeks to catalog, analyze, and visualize data sets collected by the FAA and its partners. The catalog identifies each data set and the properties of its data attributes such as completeness, consistency, etc. Researchers developed current risk-informed waiver approval practice data needs for different UAS concepts of operations (CONOPS).

Analyzing and Visualizing the Data. ASSURE analyzed the catalogued data and developed visualizations to identify insights, trends, and gaps in current data collection practices relevant to proposed UAS rulemaking and the needs of the FAA's safety management system (SMS) process. In addition, the team analyzed 3rd party UAS detection data in the vicinity of a large urban airport terminal environment to determine the validity of UAS sighting reports and UAS operator compliance with current FAA Part 107 sUAS rules.

Key Findings. The team identified gaps in current data collection practices and the data needed for operational risk assessment. Additionally, the study finds a lack of FAA guidance on UAS waiver application, indicating a need for future rulemaking to include clear guidance on safety risk management data collection requirements.

UAS detection data collected in the vicinity of the Dallas-Fort Worth International (DFW) Airport over an 18-month period (August 2018 – January 2020) censused 12,520 unique DJI sUAS across more than 162,000 separate operations. This survey identified key Part 107 compliance issues: unregistered sUAS, 4,700+ operations above 500 ft. AGL, over 200 flights within 0.5 miles of DFW, and nearly 1,100 flights within 0.5 miles of a heliport; just to name a few. The study also provides numerous other insights into sUAS operations such as density of flights as related to location and time of day, day of week, and holidays.

Recommendations based on Findings. The team's analysis provides a unique glimpse into the state of UAS integration into the NAS, informing policymakers regarding the impact of existing efforts and the data collection requirements for future efforts. These results shall support Phase 2 and Phase 3's efforts to forecast UAS demand and develop a probabilistic risk model (PRA), respectively.

The team recommends the following future research opportunities: (a) collaboration between ASSURE, FAA, and stakeholders toward the development of UAS data standards; (b) study of the impact of climate, weather, time of day, and time of year on UAS data trends to improve localized forecast of UAS demand; (c) identification of methods to collect operational data deemed sensitive (e.g. confidential or classified) permitting analysis while mitigating risk of dissemination, and (d) conducting a broader (i.e. sites nationwide) UAS detection study to census UAS operations across a variety of operating environments, characterizing the operations within those environments, (e) evaluating compliance of UAS operations with UAS rules, and (f) correlating sUAS trajectories with flight tracking data from other airspace users.

1 Introduction

Within the data rich environment of the modernized National Airspace System (NAS) and the multitude of data collection activities within the Federal Aviation Administration (FAA) to support the integration of Unmanned Aircraft Systems (UAS), the FAA seeks data driven solutions to inform its regulation/standards development efforts and inform FAA safety management systems toward the approval of new integrated UAS capabilities. These results shall inform future FAA data collection practices and data-driven probability risk assessment (PRA) frameworks.

This report presents the results of Phase 1 of the FAA's , A21_ A11L.UAS.69: Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic Trends and Safety project, sponsored under ASSURE, referenced here in as "A21." The Phase 1 research team seeks to understand (1) the current data collection practices of the FAA, (2) the relationship of the data collected to the approval of UAS concepts of operations under current and proposed Part 107 waiver authorizations, (3) identify noteworthy data trends/characteristics from the catalogued data sets, and (4) integrate the catalogued data with UAS detection and tracking data.

The effort is broadly divided into the following research activities.

Cataloging Available Data Sets. A data catalog identifies relevant data sets, their attributes and such as completeness, consistency, etc. that affect their utility in data analysis. Section 2.1 summarizes the data catalog, produced under Task 1-1, with a detailed analysis in Addendum 1 of this report.

Understanding current data collection practices. Section 2.2 summarizes Task 1-2: UAS concepts of operations (CONOPS), with analysis detail provided in Addendum 2. These examine the data requirements of safety management system (SMS)-based evaluation of UAS CONOPS.

Analyzing and Visualizing the Data. Task 1-3a, Quantitative Analysis of Available Data, is summarized in Section 2.3 with detailed analysis and visualization results discussed in Addendum 3. A quantitative analysis of the data sets and graphs within this report provides insights and trends within the cataloged data.

Waiver Requirement Data Gaps. Section 2.4 summarizes the work presented in Addendum 4 for Task 1-3b, Waiver and Notice of Public Rule Making (NPRM) Analysis toward Future SMS Data Needs. An assessment of data collection needs for future operational standards analyzed proposed rulemaking against existing data collection practices of SMS processes to identify data collection gaps (i.e., need for data standards, collection of additional data, etc.).

Validating UAS Sighting Reports with UAS Detection Data. Section 2.5 summarizes Addendum 5, which addresses Task 1-4, Visual Sightings Database Validation, which validates the UAS sightings database through the combined analysis of UAS detection data in the vicinity of Dallas-Fort Worth International Airport and the data catalogued/analyzed in the previous tasks. The team examined UAS detection data to determine compliance of current operators with UAS rules and comparison of UAS detections with other catalogued data sets including UAS registrations within the areas of operation and UAS sighting reports.

1.1 Scope and Research Questions

The purpose of this research is to collect and characterize available data sets toward the assessment of the impact of UAS integration on the national airspace system. This task is part of a broader project, ASSURE

A21, which is divided into three phases: Phase 1 (UAS data trend analysis), Phase 2 (forecast of future UAS trends), and Phase 3 (development of a data-driven safety risk assessment framework). This report addresses only Phase 1 of this study.

The research is divided into five research tasks[1]. Each has its own set of goals and research questions.

Task 1-1, Data Set Assessment. The research team shall develop a data catalog which will identify available data sets to support the efforts of this study. The University of North Dakota (UND) led Task 1-1. Research questions for this activity include:

- What data fields are included? How are they defined? In what format? How were these data collected (including indications of completeness, reliability, and validity)?
- Where is the data stored and how is it accessed?
- What analysis techniques are suitable for the data sets?

Task 1-2b Data Needs for CONOP Evaluation. To understand future trends in UAS operations and to identify the data elements necessary to assess the safety and operational characteristics of a UAS, the researchers seek to analyze existing UAS CONOPS and waivers to articulate the types of operations and examine SMS approaches to assessing an operation and/or aircraft's airworthiness. UND led this research task with the following research questions: What are current UAS CONOPS relevant to small UAS expanded operations including operations over people and other waiverable UAS integration activities?

- What performance metrics must be considered toward determining the performance of UAS CONOPS?
- What data is necessary to evaluate actual or predicted performance under the CONOPS?

Task 1-3a, Quantitative Analysis of Available Data. Given the catalogued data, Task 1-3 explores the catalogued data to determine what insights and trends can be made from the data, how the data set can be improved to obtain future insights, and the suitability of sightings data to forecast future unmanned/manned encounter report frequency. This research task, led by Embry-Riddle Aeronautical University (ERAU), addresses the following questions:

- What are the quantitative characteristics of the data set (i.e., number of records, sparsity of data, etc.)?
- What is the set of most informative quantitative analyses of current activities both within and across different data sets that can be provided, including trend analyses?

Task 1-3b, Waiver and NPRM Analysis toward Future SMS Data Needs. A second activity of Tasks 1-3 is to assess waiver and NPRM-defined requirements for data reporting as part of the safety risk management (SRM) process. The team maps elements from the FAA requirement documents to a node-hierarchy of SRM tasks and sub-tasks to determine which SRM activities require further detail including the identification of data requirements. Led by ERAU, this task addresses the following questions:

- What trends exist with Part 107 waiver activity and NPRM regulatory language?
- What SMS processes govern the analysis of waiver applications, and the data requirements to validate each?

[1] The research team has divided Task 3 into Task 3a and Task 3b to distinguish quantitative analysis of existing data versus qualitative analysis of FAA documentation for data needs identification, respectively. Each address independent research questions.

Task 1-4, Visual Sighting Database Validation. The final activity integrates UAS sighting report data with UAS detection data provided by the DJI AeroScope at Dallas-Fort Worth International Airport. The researchers seek to better understand the validity of using reports of UAS sightings near aerodromes or other aircraft that could potentially, but not necessarily, result in a safety hazard/violation of operating limits. ERAU researchers address the following research questions:

- Where is the preponderance of UAS sightings occurring?
- Where is UAS activity detected that is not being reported?
- How accurate are UAS sighting reports when compared with alternative UAS detection methods?
- Can any data trends be identified to codify specific human factors or perceptual errors?
- What proportion of UAS sighting reports meet Near Midair Collision (NMAC) criteria?

1.2 Organization of this Document

This document is organized such that the research of Phase 1 is summarized within Section 2 including research findings and recommendations. A summary of research conclusions is presented in Section 3. Each research task's detailed analysis is provided within an addendum to the document:

- Task 1-1 - Addendum 1: Technical Report – Data Set Assessment
- Task 1-2 - Addendum 2: Technical Report – Data Needs for CONOPS Evaluation
- Task 1-3a - Addendum 3: Technical Report – Data Analysis
- Task 1-3b - Addendum 4: Technical Report – Waiver and NPRM Analysis
- Task 1-4 - Addendum 5: Technical Report – Visual Sightings Database Validation

Following the addendums, appendices service as reference including Appendix A1: Use Case Definitions from A18, which summarizes the use case definitions used in Task 1-2.

2 Overview of Research, Findings, and Recommendations

This section provides a summary of each of the major research tasks. Technical reports for each task are provided as addendums to this report.

2.1 Data Set Assessment

The research team acquired UAS data sets from multiple sources and developed a data catalog to establish an understanding of available data types, categories, and uses. The analysis also sought to characterize the data with respect to completeness, presence of non-physical/errant entries, and data inconsistencies. A detailed technical report of this effort is presented in Addendum 1.

Task 1-1 of A21 seeks to identify, acquire, analyze, and catalog data sets that provide insights into expanded and integrated UAS operations. The sub-tasks are:

1. Develop master list of data sets.
2. Document the formats associated with the data sets.
3. Document data elements associated with the data sets.
4. Determine utility of data sets by relating to data elements that are identified by the team as being needed for the analysis.
5. Develop a plan for accessing data sets, including multiple approaches when possible to maximize the likelihood of timely reception of the data.
6. Determine applicable restrictions (proprietary, IRB, etc.).
7. Characterize the data sets (descriptive statistics) and produce a data catalog.
8. Acquire data by coordinating with the data collection team.

The A21 team developed a data catalog, in the form of a Microsoft™ Excel™ workbook, to describe data sets. This catalog's organizational structure emulates the organization used in Ahmed et al. (2017)In developing this catalog's organizational structure emulates the organization used in in Ahmed et al. (2017). Table 4 presents the data catalog and is found in Section 4.2 (in Addendum 1).

The catalog is organized into the following sections:

- Data that have been acquired by the A21 team
- Registration: Data providing information regarding Unmanned Aircraft (UA), pilots, and locations
- Intent: Data elements describing intended uses of UA
- Platforms and Models: Provides information regarding UA
- Company-Level Data: Information regarding manufacturers of UAS and UAS components
- Tracking and Trajectory: Information regarding flight tracks and trajectories
- Safety: Data related to safety of UAS operations

Numerous UAS data sets have been acquired. These data have been acquired through multiple means, including:

- Acquisition of publicly available data from data repositories
- FAA provision of data (without a formal request from A21 performers)
- FAA provision of data in response to A21 performer requests
- Agreements developed by individual A21 performers

Owing to data restrictions (propriety data, etc.), the FAA rejected some data requests. These restrictions pose a significant challenge, as lack of data can undermine the team's ability to develop an accurate picture of current and predicted expanded and integrated UAS operations. Development of a data sharing construct that enables access to data while preventing inappropriate data exposure beyond the A21 team would enhance the value of A21 research.

Evaluated data sets include:

- UAS sightings data
- Approved Part 107 waivers
- Mission Loggins Logging System (MLS) data

UAS sightings data were determined to be complete. MLS data, however, have data element availability that ranges from 0% to 100%, which is consistent with many MLS data fields being optional. In addition, non-physical entries were identified in five MLS flight operations data fields and in two MLS accidents/incidents fields, with the latter being associated with inconsistencies in data entry (e.g., Class G vs. G). Analysis of Part 107 waivers provided significant insights into mitigations and restrictions for approved operations. Researchers performed both manual and algorithmic (computer code-based) analysis techniques on the waivers. The structured format of the Part 107 waivers enabled automated analysis. Limits to the structured format, however, resulted in a need for manual efforts to complete the analysis.

Numerous UAS data sets have been acquired from multiple sources (e.g., public websites, the FAA, private sources). To understand the breadth and types of UAS data, the research team developed a data catalog. This catalog provides data categories, types of data provided by data sets, and information regarding data acquisition. Some data sets are being utilized to predict trends associated with UAS. Those data have and are being analyzed to understand data characteristics including completeness, presence of non-physical/errant entries, and data inconsistencies.

2.2 Data Needs for UAS CONOP Evaluation

Task 1-2 of A21 seeks to determine the FAA's data needs to drive risk-based analysis of UAS systems toward specific CONOPS. This task sought to determine current sUAS CONOPS for expanded operations under Part 107 waiver such as those permitting operations over people. The team determined the applicable the performance metrics enabling the assessment of the safety of UAS CONOPS, and what data would be required to evaluate the actual or predicted performance under CONOPS.? Addendum 2 presents the technical report for Task 1-2 including its exhaustive review of UAS CONOPS, evaluation of data needs, and recommendations.

The research questions/goals being addressed are:

- What are current UAS CONOPS relevant to sUAS expanded operations including operations over people and other waiverable UAS integration activities?
- What performance metrics must be considered toward determining the performance of UAS CONOPS?
- What data are necessary to evaluate actual or predicted performance under the CONOPS?

The following subtasks address these research goals:

1. Review relevant CONOPS based on existing CONOPS available for relevant organizations and based on inferences from waiver requests
2. Identify data needed to evaluate actual or predicted performance under those CONOPS
3. Solicit additional CONOPS from ASSURE partners, Integration Pilot Program (IPP) participants, and UAS test sites
4. Complete survey of current UAS CONOPS as identified within the project scope for expanded operations of sUAS

5. Complete survey of current safety assessment metrics and methodologies for UAS waiver approval for identified CONOPS
6. Identify data collection requirements for CONOPS safety assessment
7. Identify existing data sets supporting CONOPS evaluation
8. Identify data gaps that must be necessarily addressed for CONOPS evaluation

2.2.1 CONOPS Review

The research team leveraged past research results from the ASSURE A2[2] and A18[3] projects, which previously defined a significant number of sUAS CONOPS for expanded operations. A taxonomy of CONOPS and use cases are summarized in Section 5.2 of the report (in Addendum 2).
Table 8 summarizes use case applications of expanded Beyond Visual Line of Sight (BVLOS) and Detect and Avoid (DAA)-enabled operations.

The team found the CONOPS leveraged from A2 and A18 provided tremendous granularity for some classes of CONOPS. However, examining the FAA's proposed operational capabilities of the FAA's *UAS Integration Research Plan (UIRP)* (Stande 2019). The previously identified CONOPS/use cases align with its operational capabilities areas Operations Over People, Expanded Operations, Non-Segregated Operations, and Routine/Scheduled Operations. CONOPS were not identified for other capability areas including small UAS package delivery, large carrier cargo operations, and passenger transport operations.

The focus herein is on sUAS and on the elements in
Figure 12 (in Addendum 2) up through Routine/Scheduled Operations.

2.2.2 Survey of Data Needs for CONOP Evaluation

The team's recommendation for UAS CONOPS evaluation data requirements is based upon the FAA's rejection/acceptance of waiver applications for UAS operations under Part 107, i.e., expanded UAS operations. A request from the research team for UAS waiver applications with their dispositions was not accepted. The project sponsors worked with the team to determine the frequent cause for waiver rejection. The team leveraged the FAA's published waiver approval letters to evaluate the information necessary to establish a safety case.

Lessons learned from rejected Part 107 Waivers. Part 107 waivers are rejected because, in a simple sense, the associated safety cases are insufficient. A trend analysis has been completed for both 107.31 (BVLOS) waivers and 107.39 (Operations over People) waivers (FAA, 2020c). For BVLOS, waiver deficiencies included insufficient command and control (C2) link information; lack of information regarding the UAS's DAA performance and procedures; failure to identify how environmental hazards will be mitigated; and insufficient information on crew qualifications and/or training. For Operations Over People, waiver applications were found deficient by failing to identify the ground collision severity of the operation (i.e., impact of an incident/accident); mitigations against laceration injuries; failure to identify operational limitations, conditions, and procedures; and insufficient documentation of pilot experience necessary for safe operation over people.

Further correspondence with the sponsors regarding rejected waivers identified that the waiver rejections are due to inadequate CONOPS descriptions, inadequate description/demonstration of safety measures, and/or inadequate description of flight environment and vicinity information (e.g., population density) (D.

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[2] A11L.UAS.22 Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations (referred to as A2)
[3] A11L.UAS.22 Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations (referred to as A18)

Bhadra and M. Lukacs, personal communication, 13 August 2020). The sponsors indicated that evaluation of Part 107 waivers to identify future areas of demand has not been completed. Doing so would be possible given trends observed with some CONOPS (e.g., linear infrastructure inspection). Importantly, once a CONOPS is approved, that approval provides a "template" that others can utilize, resulting in an increase in operations associated with that CONOPS.

Lessons Learned from Part 107 Approval Letters. Approved Part 107 waivers provide insight into CONOPS and data associated with CONOPS. The team constructed a data set of approved Part 107 waivers extracted from the FAA's Part 107 website on 18 April 2020 (data set spans 15 June 2016 to 18 April 2020) as PDF files from which the team extracted pertinent information as discussed in Section 5.3.2 (in Addendum 2).

Methodology. Approved Part 107 waivers were analyzed to identify types of mitigations that used and any restrictions on authorized operations. *Mitigations* are enabling technologies and/or procedures that enable an operation. *Restrictions* are requirements that must be followed for the operation to proceed. The line between restrictions and mitigations can be blurred, e.g., some restrictions are considered a mitigation approach. The types of Part 107 waivers examined include:

- Part 107.31 – Beyond Visual Line of Sight (BVLOS)
- Part 107.35 – Flying Multiple Small Unmanned Aircraft Systems (sUASs)
- Part 107.39 – Flying Over People
- Part 107.51b – Operating Limitations: Altitude Above 400 ft Above Ground Level (AGL)
- Part 107.51c – Operating Limitations: Minimum Visibility
- Part 107.51d – Operating Limitations: Minimum Distance from Clouds

Night operations, the largest waiver category, were not included in the analysis as it is presumed that this type of operation follows all other Part 107 requirements except for its operation at night, which does not elevate it enough to be an "advanced" operation such as BVLOS or operations over people.

Analysis of Mitigations. The waiver analysis revealed that visual observers (VOs) appeared to be the most frequently employed mitigation strategy. For BVLOS, a leading emergent use case only utilized DAA technologies for four waivers, of which two also utilized visual observers. These results indicate that establishing DAA technology that can be proven to provide enough mitigation to achieve a desired level of safety is a major barrier to advanced (BVLOS) operations. Chase aircraft were not reported for any of the Part 107 waivers.

Table 1: Analysis of Part 107 waivers issued by mitigation type.

Waived Section	Title	No. Waivers (N=)	No. Waivers by Mitigation					
			Visual Observer(s)	DAA Tech	Onboard Camera(s)	Chase Plane(s)	Tether	Unknown
Part 107.31	Beyond Visual Line of Sight (BVLOS)	47	44	4	2	-	2	-
Part 107.35	Flying Multiple Small Unmanned Aircraft Systems (sUASs)	49	48	-	-	-	-	1
Part 107.39	Flying Over People	114	110	-	2	-	4	-

Part 107.51b	Operating Limitations: Altitude Above 400 ft Above Ground Level (AGL)	39	39	-	-	-	-	-
Part 107.51c	Operating Limitations: Minimum Visibility	13	10	-	2	-	2	-
Part 107.51d	Operating Limitations: Minimum Distance from Clouds	13	10	-	2	-	2	-

For Part 107.35 and 107.51b, except for one Part 107.35 waiver, the team found that visual observers served as the risk mitigation strategy used. Beyond these two waiver types, multiple mitigation strategies were used for each. The researchers did note that none of the waivers identified the number of VOs to be utilized, type of DAA technology employed, or onboard camera specifications used for approved operations.

Analysis of Restrictions. Nearly all surveyed waivers required multiple restrictions. The types of restrictions included within the waiver acceptance letter varied by operation type(s) requested. The thirteen general types of operational restrictions identified include: Notice to Airman (NOTAM) requirement(s), height/altitude, groundspeed, windspeed, class G airspace only, restrictions on operations over people (participants AND non-participants), range of the sUAS from VOs or ground-based DAA technologies, cloud ceiling, visibility, restrictions on operations over moving vehicles, maximum aircraft weight, aircraft make/model to be used, and limited to daylight hours only. Table 2 presents the number of waivers utilizing which require each mitigation strategy aggregated for each of the Part 107 provisions waived.

In Section 5.3.2.3.2 (in Addendum 2), a more detailed breakdown of the restrictions by waiver type is provided. Part 107.31 waivers were largely restricted by NOTAM requirements followed by altitude limits and operation within class G airspace with a variety of other operational parameters restricted at a lesser frequency. Part 107.35 operations are largely restricted to class G airspace with a NOTAM requirement, and a several waivers were restricted to specific airframes. Part 107.39 places specific restrictions impacting safety for operation over people including limits on flight altitudes. Out of 114 waivers, 90 waivers contained a restriction (or, functionally, an allowance) for flying over people. Within this restriction, most of the waivers contained another restriction that stated the sUAS must be equipped with a parachute system in order to fly over people. The primary parachute systems used were the ParaZero SafeAir Mavic and the ParaZero SafeAir Phantom. Part 107.51b's waivers on the 400 ft AGL altitude limit primarily placed restrictions on NOTAM requirements and the requested operational ceiling. Lastly, waivers for both 107.51c and 107.51d, addressing minimum visibility and distance included the same set of waivers with restrictions, which in addition to NOTAM and altitude requirements addressed operational limits based directly on those metrics, distance to cloud, and range of visibility.

2.2.3 Recommendations toward Data Collection for UAS CONOP Evaluation

From the survey of CONOPS and the analysis of UAS waivers, the team can provide some recommendations for data requirements under the operational contexts covered (BVLOS, operations over people, and operations over moving vehicles). Section 5.4 (in Addendum 2) presents the team's recommendations with respect to data needs by operational context (Table 9) and data sources to fulfil those needs (Table 10).

Access to a complete set of UAS waiver applications with their dispositions was not available to the team, which limited the analysis to a high-level review of accepted waivers and prevented a comprehensive gap analysis for each category. However, the fundamental data needs were identified as clear definition of the operational context (including system limitations), defined metrics and performance requirements under each, and test data that illustrates conformance with the performance requirements/expectations within the operational context.

Two ASSURE efforts, A19 and A20, are developing systems for collection of both test and operational data. These efforts are expected to enhance not only collection of data regarding UAS CONOPS, but also evaluation of progress regarding CONOPS (including aggregated data) and needs for further research. It is expected, then, that the efforts herein and in related efforts will accelerate realization of UAS CONOPS.

Table 2. Analysis of Part 107 waivers issued by restriction type.

Waived Section	Title	No. Waivers (N=)	Waivers by Restriction												
			NOTAM	Height	Ground- speed	Wind speed	Class G Airspace	Ops Over People	sUAS Distance from VOs/Tech	Cloud	Visibility	Ops over Moving Vehicles	Aircraft Weight	Aircraft Make/ Model	Daylight Hours Only
Part 107.31	Beyond Visual Line of Sight (BVLOS)	47	26	12	7	10	2	7	2	-	1	-	-	-	-
Part 107.35	Flying Multiple Small Unmanned Aircraft Systems (sUASs)	49	41	18	14	0	29	8	3	-	0	1	-	8	-
Part 107.39	Flying Over People	114	5	90	4	6	7	1	2	-	1	5	80	23	-
Part 107.51b	Operating Limitations: Altitude Above 400 ft Above Ground Level (AGL)	39	39	39	0	-	4	-	-	-	0	-	-	39	-
Part 107.51c	Operating Limitations: Minimum Visibility	13	9	11	6	-	5	1	3	9	13	-	-	13	4
Part 107.51d	Operating Limitations: Minimum Distance from Clouds	13	9	11	6	-	5	1	3	9	13	-	-	13	4

2.3 Quantitative Analysis of FAA Data Sets

To understand the impact and recent trends of sUAS integration, researchers performed quantitative data analytics across the catalogued data sets. The data sets provide insight into the changes in airspace demand and utilization, frequency of UAS sighted near airports or other aircraft, the distribution of UAS operations spatially, etc.

Leveraging the data catalog produced in Task 1-1 and the greater understanding of UAS CONOPS from Tasks 1-2, the research team performed quantitative data analysis on UAS registration data for Section 336 (hobbyist) and part 107 (civil/commercial) operators; remote pilot in command (RPIC) certification databases; UAS facility maps; UAS certificates of authorization issued; Part 107 exams and exam results, Mission Logging System operations and incident/accident reports; national UAS sightings incidents/accidents; and Part 107 waiver acceptance letters.

Addendum 3 presents the technical report for Task 1-3's quantitative analysis. The research team summarizes the data preparation activities including data clean-up, integration, and aggregation necessary to transform the raw FAA data into data sets suitable for data analytics tools and techniques. Quantitative analysis and data trend analysis is provided for UAS registrations/pilot certificates, Part 107 waivers issued, operational data from FAA UAS Test Site, and UAS sightings data.

This research effort sought to address the following research questions:

- What are the quantitative characteristics of the data set (i.e., number of records, sparsity of data, etc.)?
- What is the set of most informative quantitative analyses of current activities both within and across different data sets that can be provided, including trend analyses, and completed?
- What trends exist with Part 107 waiver activity and NPRM regulatory language?

This effort is addressed by first performing data preparation followed by quantitative analysis of the data sets. Forecast analyses are also included to assess the suitability of the data sets to forecast future data trends.

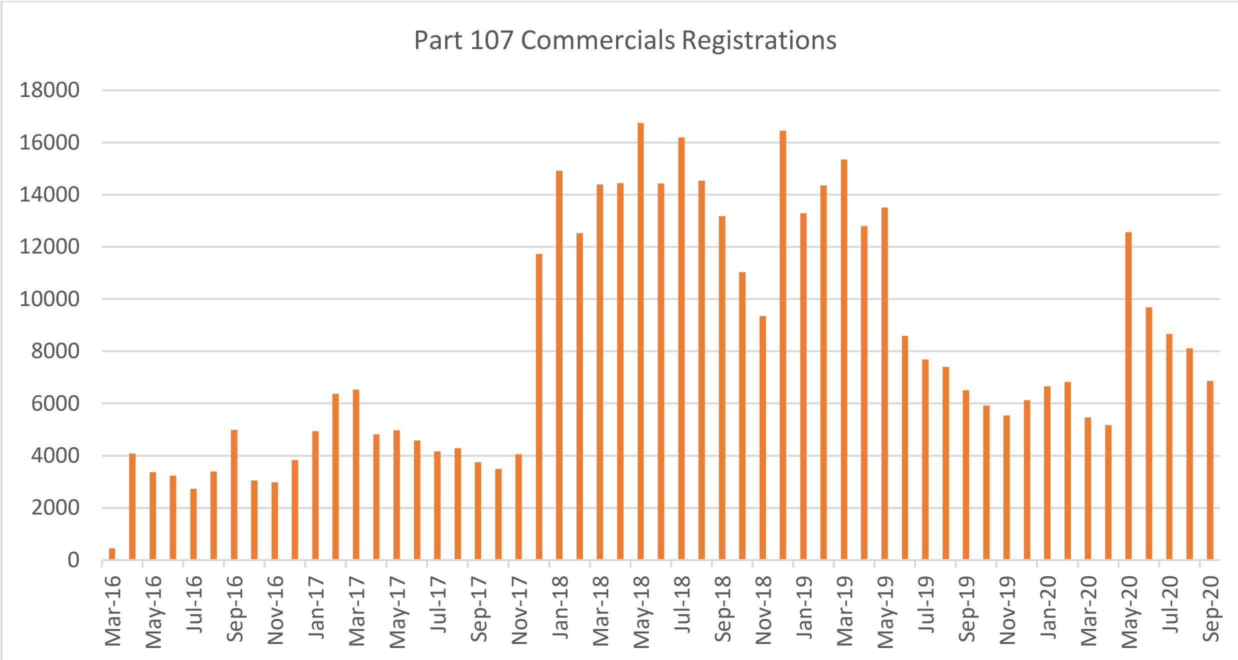
2.3.1 Data Preparation

The data preparation tasks include data cleaning, transformation, and merging for quantitative analysis. The researchers used Microsoft ™ Excel™ for data exploration and preparation. To ensure the usability of the data, by scrutinizing the attributes of each data set, the team identified unusable attributes. For example, UAS sighting incident data included some reports with too many missing attributes to support the analysis or construction of a data model. Irrelevant data were also identified such as data for the sighting data the free-form text describing each event, which was deemed not suitable to the assessment (i.e., it lacks a common format or information requirement). The research team identified specific data preparation actions to be taken for each applicable data set in Section 6.3 (in Addendum 3).

2.3.2 Overview of Data Analysis Results

This section summarizes the analysis results presented Section 6.4 (in Addendum 3). It identifies the data sets analyzed, a summary of insights from the data, and any additional recommendations. Detailed figures and analysis are presented within the addendum.

Registration and Pilot Certificates. The research team used descriptive statistical analysis and visualization to assess the UAS registration data and remote pilot certificates issued across several data sets. Registration data is broken down by registration type (Section 336, hobbyist, or Part 107, civil/commercial) and month issued. The number of remote pilot certificates issued are also aggregated by month; however, RPIC examination results were provided by the FAA aggregated quarterly. Figure 1 presents the number of Part 107 UAS registrations correlated with UAS integration milestones, which following a brief lag in time implies that the milestones such as Low Altitude Authorization and Notification Capability (LAANC)/IPPs cause an increase in demand for registration of new systems. Figure 2 shows remote pilot in command (RPIC) certificates issued under two conditions: a remote pilot certificate for hobbyists or Part 61 plus a remote pilot certificate option) with milestones labeled, which show overall modest growth trends following several milestones as well as an overall trend of Part 61 pilots receiving RPICs decreasing while new pilots seeking Part 107 certificates increasing over the surveyed period.



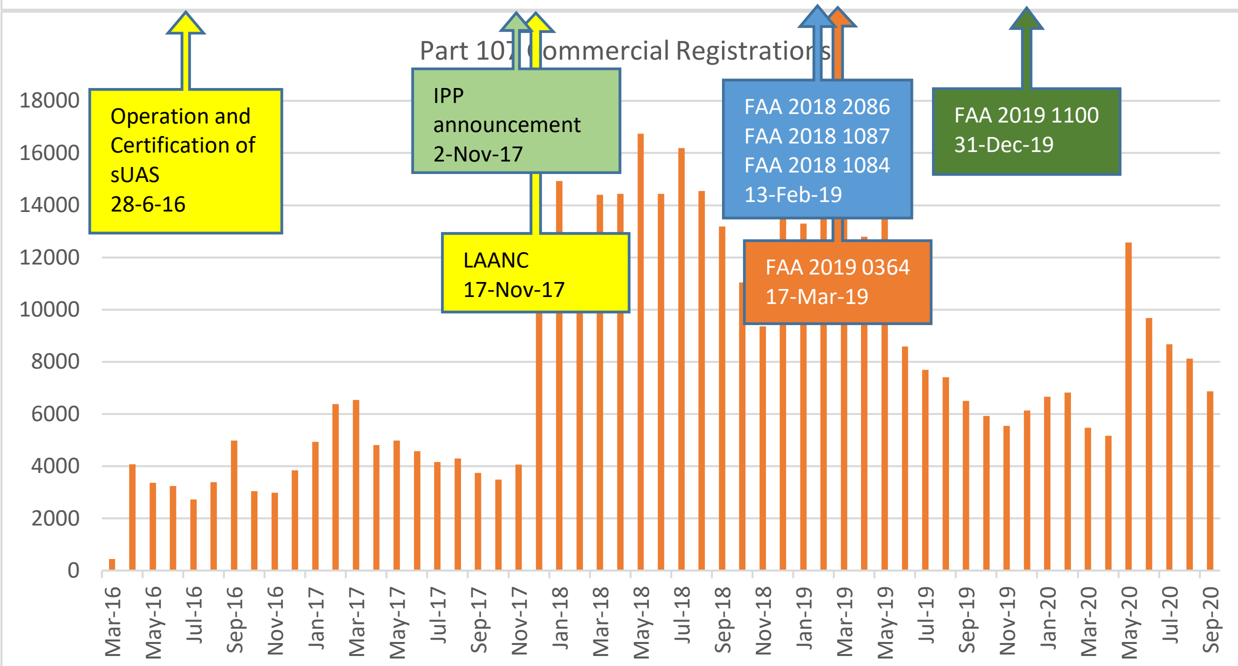


Figure 1. UAS registration numbers in the United States - Commercials (Part 107) with milestone dates.

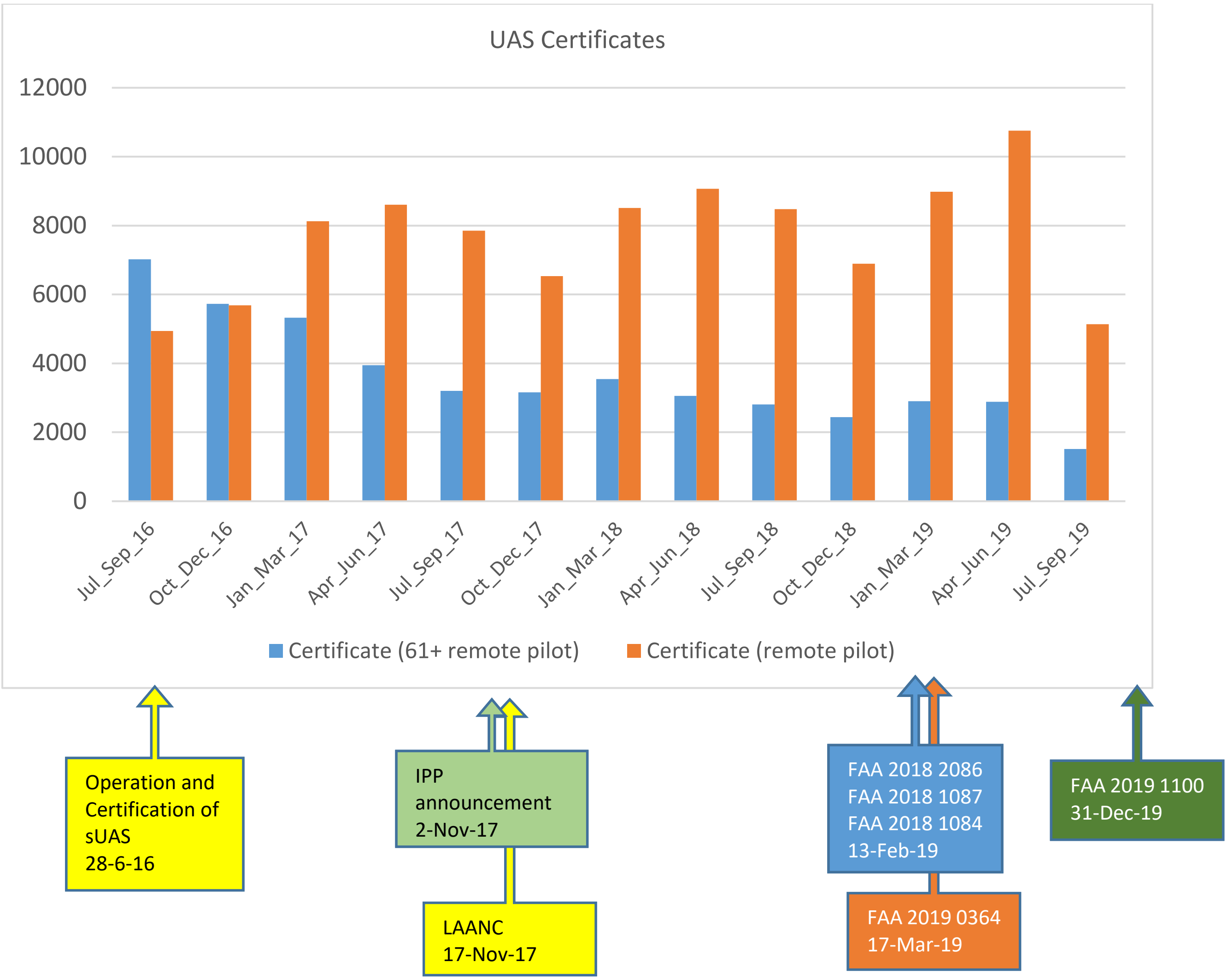


Figure 2. UAS Certificates in the United States with milestone dates.

Approved Waivers. Section 6.4.2 (in Addendum 3) presents the research team's analysis of approved waivers via descriptive statistical analysis and visualization. This research is complementary to the analysis on waivers performed under Task 1-2 (see also Sections 2.2.2 and 5.3.2). Figure 3 presents a bar graph of the total number of UAS waivers accepted over the survey period from Q3 2016 through Q2 2020. The analysis also compares waivers issued for IPP related projects versus non-IPP waivers, but IPP waivers were the least frequent with a maximum issued over a one-month period being 9 in August 2019. Since early 2019, a steady increase in monthly waivers can be observed until a decline in waivers beginning in March 2020, which can likely be attributed to the impact of COVID-19.

As per communications with the FAA, the project sponsor provided additional insight regarding waiver application trends. Waiver applications are categorized as: highly complex, moderately complex, simple/routine, team analysis, emergency ops, IPP waivers, undetermined, or missing complexity value.

Categorization based on complexity is attributed to (a) operational complexities, (b) ground and air risk, and (c) repeatability/scalability of waived activity.

Communications with FAA also reveal that submissions of simple/routine Part 107 waivers make up the largest portion of the program's workflow (N=14,844) with significantly fewer waivers which follow workflows based on complexity, including moderately complex (N=802) and highly complex (N=976) waivers. The communications also revealed that the success rate of Part 107.29 (Daylight operations) waivers is highest at nearly a 30% success rate, while Part 107.25, operations over moving people, has had zero successful waivers issued as of August 2020.

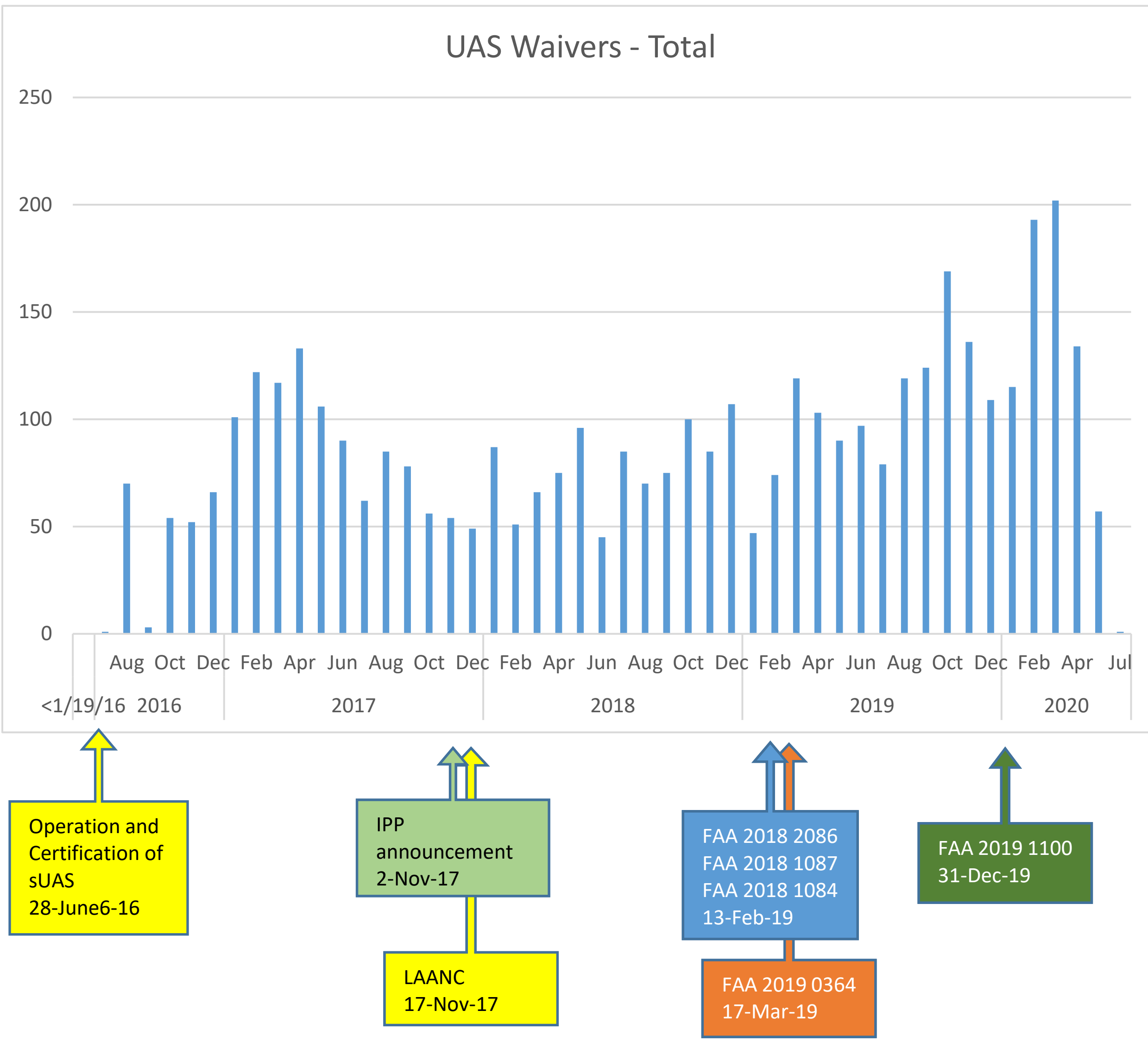


Figure 3. UAS Waivers – Total issued waivers by month with milestone dates.

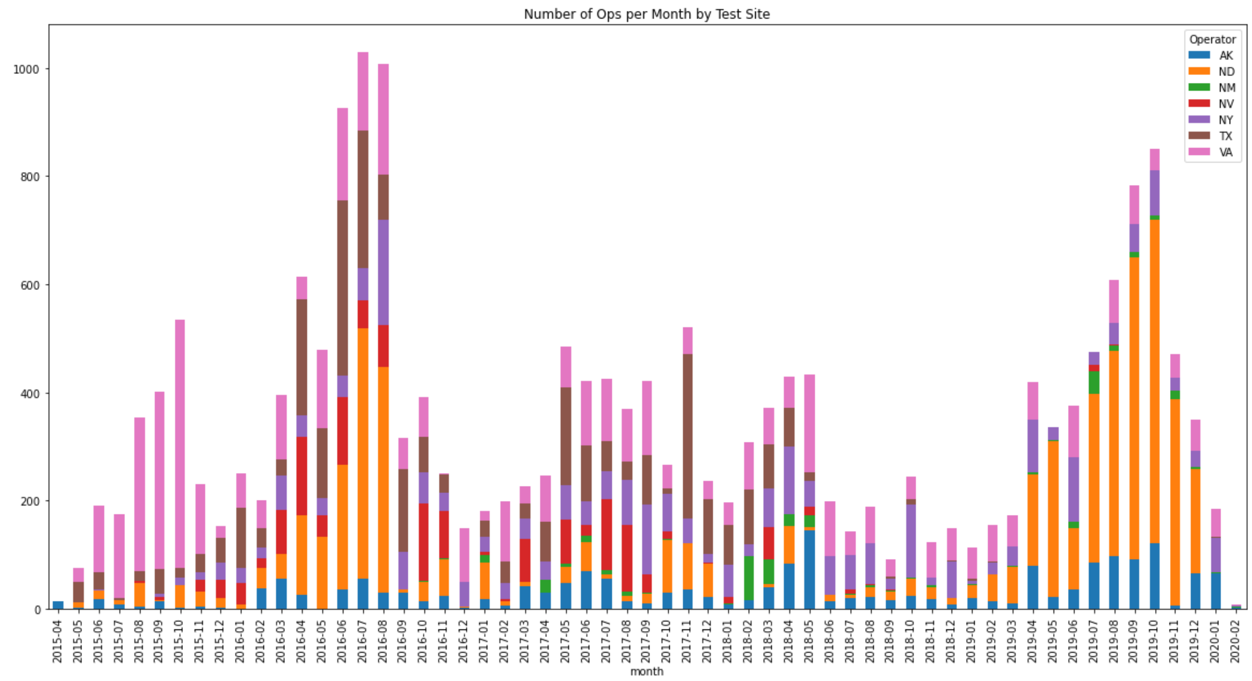
MLS Operations and Incident/Accidents. FAA's UAS test sites collect operational data in the Mission Logging System (MLS). The research team analyzed and characterized the operations performed and reported incidents/accidents from each test site. Table 3. FAA UAS Test Sites. Table 3 shows the seven FAA UAS Test Sites (FAA, 2020b). Detailed analysis of the number of monthly UAS operations and the total flight hours compared by test site, UAS weight category, line-of-sight type (LOS, BVLOS, or EVLOS), altitude ceiling, and airspace class are presented in Section 6.3.4 (in Addendum 3).

This overview of the results shall focus on the number of operations by test sight and aircraft weight class. Figure 4 and Figure 5 plot the number of operations at UAS test sites plotted by the test site (labeled as "operator" based on data set's labels) and by aircraft weight category, respectively. The number of activities by test site varied but did show an increase in the frequency of operations around major test/demonstration events. Quarters 2 and 3 of 2016 included the highest period of activity with a trending increase in test site activity beginning in April 2019 with a noticeable increase. Next, it followed by a growth trend through October 2019 (after which the plots show a seasonal decline). Figure 5 shows a clear trend in the size of UAS evaluated at test sites increasing as earlier operations were primarily focused on smaller UAS with more recent analysis largely focused on large sUAS systems.

Table 3. FAA UAS Test Sites.

Site Name	State
Griffiss International Airport	NY
New Mexico State University	NM
North Dakota Department of Commerce	ND
State of Nevada	NV
Texas A&M University-Corpus Christi	TX
University of Alaska Fairbanks	AK
Virginia Polytechnic Institute & State University	VA

The team observed that significantly fewer incident and accident reports within the MLS database than anticipated, which the researchers note could be a result of underreporting. The NV test site reported the most incidents of 9 cases. Additionally, 21 of 54 reported events resulted in accidents and one reported an aircraft collision. The remaining incidents were reported as lost link or equipment malfunction events. It is important to note that due to the number of missing values, the total number of incidents does not always add up.


Number of Ops per Month by Test Site
Operator
AK
ND
NM
NV
NY
TX
VA
month

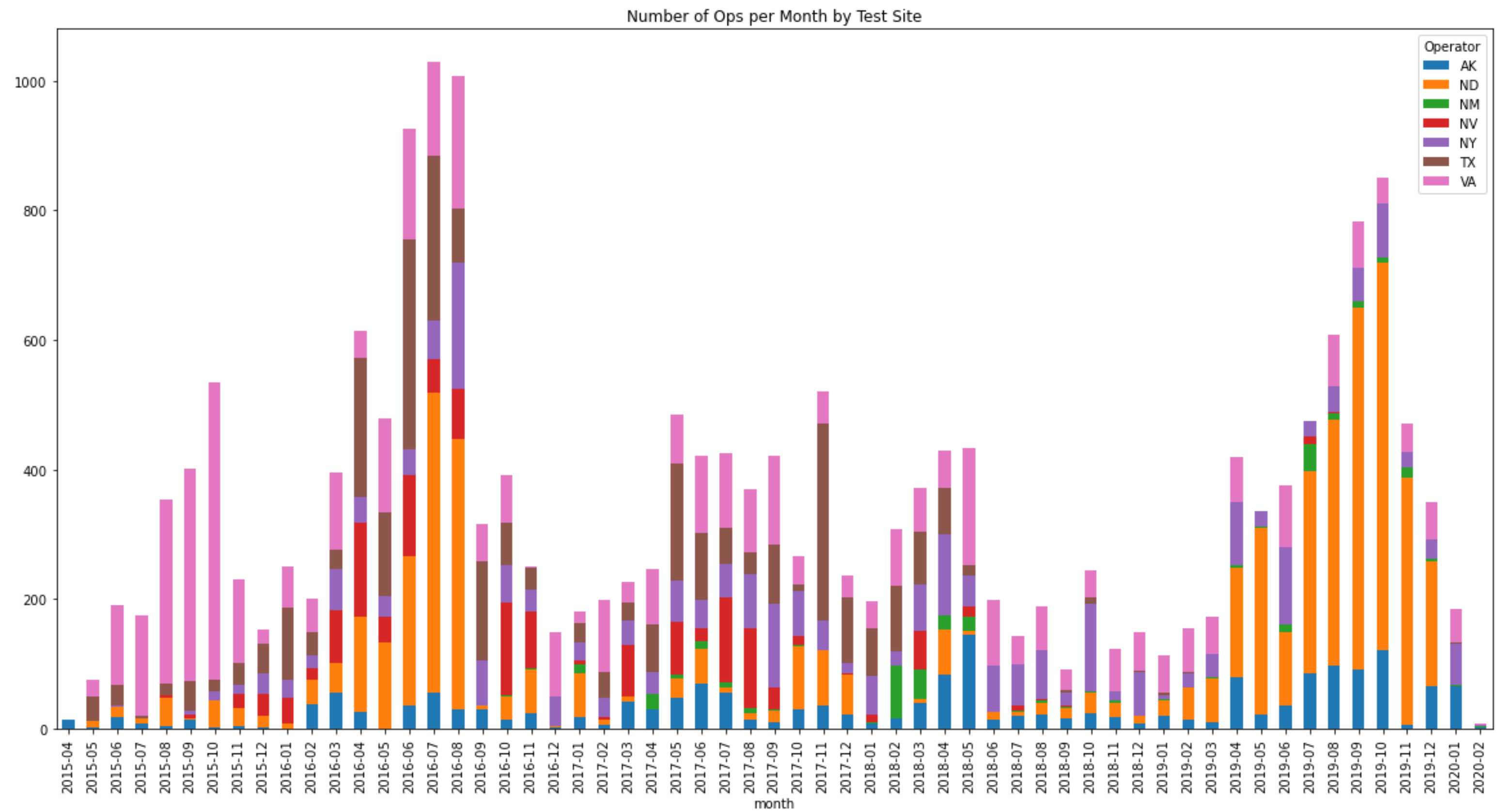


Figure 4. MLS operations by test site state.

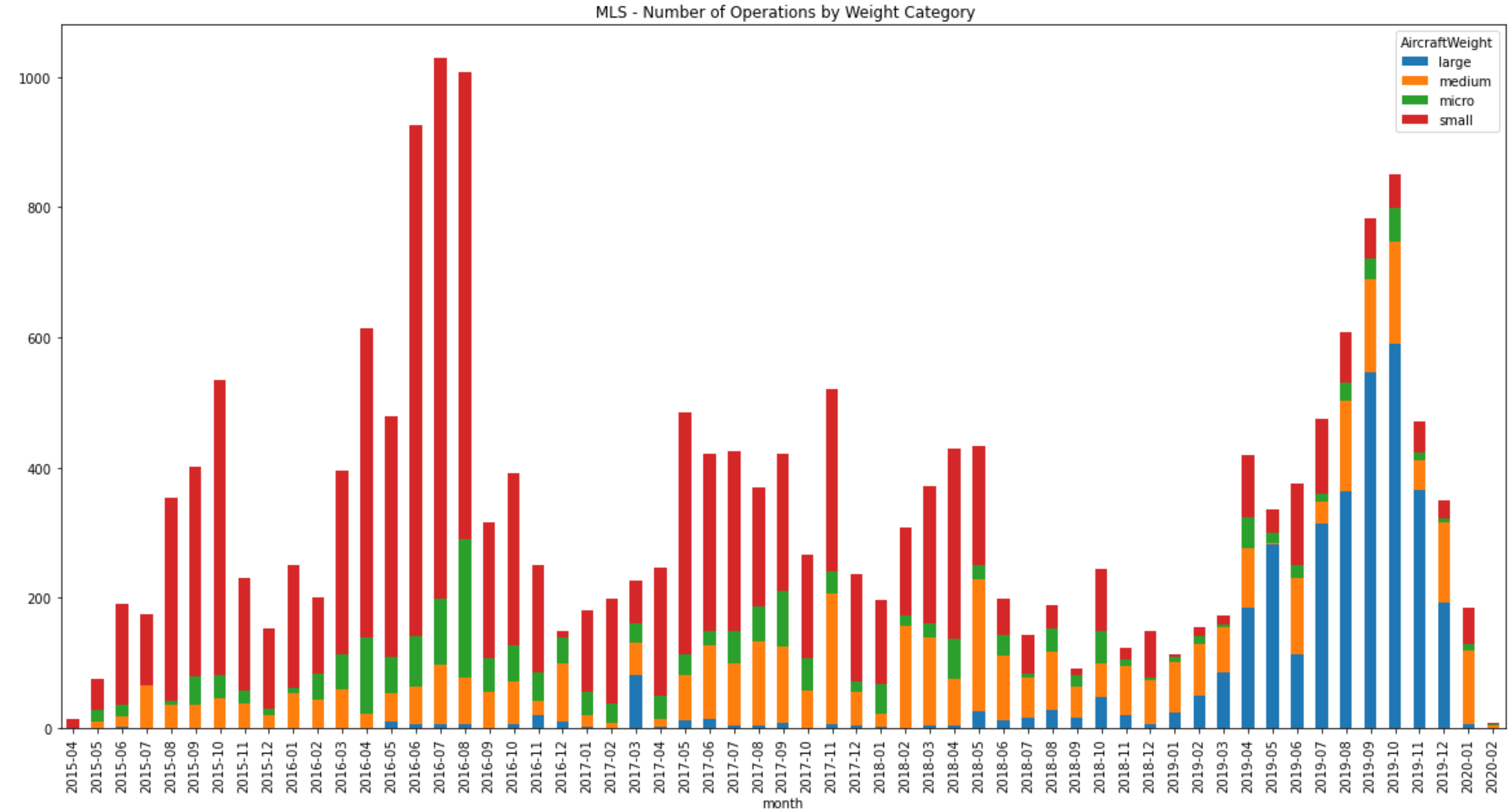
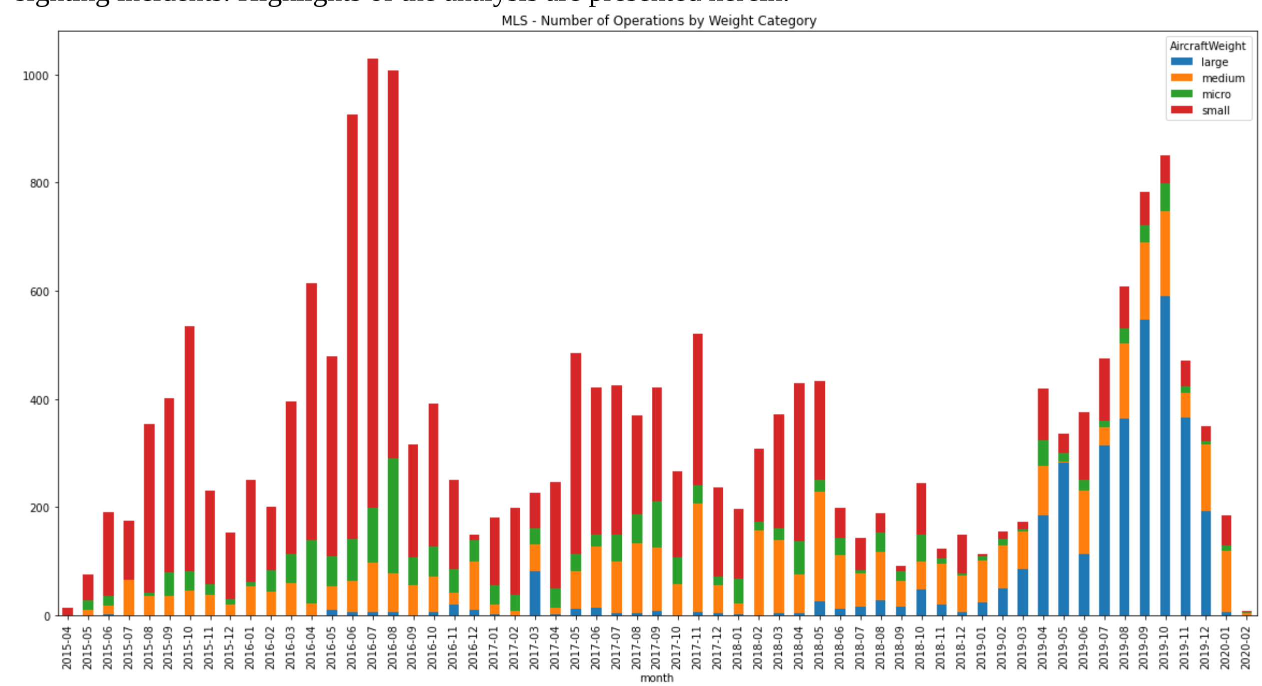


Figure 5. MLS operations by UAS weight category (micro: under 5 lbs.; small: 5-55 lbs.; medium: 55-300 lbs.; large: 300+ lbs.).

Sighting Report Data. The data set of reported incidents of UAS sighted too close to airports or other aircraft presented challenges to the research team as much of the sighting event details are captured within a free-form text field, which makes quantitative analysis difficult if not impossible in some circumstances. To analyze the sighting report data, word clouds analyze the sighting descriptions to illustrate the frequency of words used within the reports. The team plotted the reported sightings by month nationally and by each of the nine NOAA climate regions. To assess the suitability of the data set for predictive modeling to develop forecasts of sighting frequency (as a potential indicator of risk), the team developed an Auto Regressive Integrated Moving Average (ARIMA) time-series forecast for each of the ten time-series (national count plus nine counts by NOAA regions).

Section 6.4.4 (in Addendum 3) comprehensively presents the analysis of the data from reported UAS sighting incidents. Highlights of the analysis are presented herein.



The word cloud revealed that the most frequently used words include: drone, reported, pilot, notified, feet, and evasive. However, words like "B737" and "C172" present within the word cloud indicating reports of interactions with manned air traffic. Unfortunately, no deeply informative insights could be gained from quantitative analysis means from the incident description

Figure 6 shows the national sighting report counts by month. Annual trends can be observed in which the number of sightings decreases during winter months and increases during summer months. This correlates to the expectation that UAS operations happen more frequently during warmer months. These cyclic trends hold regionally as well with some variability as expected based on regional climate.

Nationally and for each of the nine NOAA climate regions, the team visualized the sightings data by the hour of day of the reported event, adjusted to the local time of day. Figure 7 presents the nationwide scatterplot of events vs. date and time of day. The figure reveals that the sighting reports largely occurred within daylight hours with more late-evening sightings than early morning sightings. The regional figures reveal a greater number of sighting reports within the West, North East, and South East regions with the West providing the most year-round sighting reports. By state, California reported approximately 700 sightings while the next three highest are Florida, Texas, and New York with approximately 400 sightings reported. The colors used within the plot vary by calendar year to help the reader visualize annual trends.

Figure 8 demonstrates the performance of an ARIMA forecast model utilizing the observed number of sighting incidents to predict the future number of sighting incidents. Confidence intervals of 95% are also plotted. The team found a forecast model could be implemented, but given the noisy nature of the data, predictions could not be made with a high-level of confidence. Analysis performed regionally showed greater susceptibility to noise due to the smaller set of data used to train models for each.

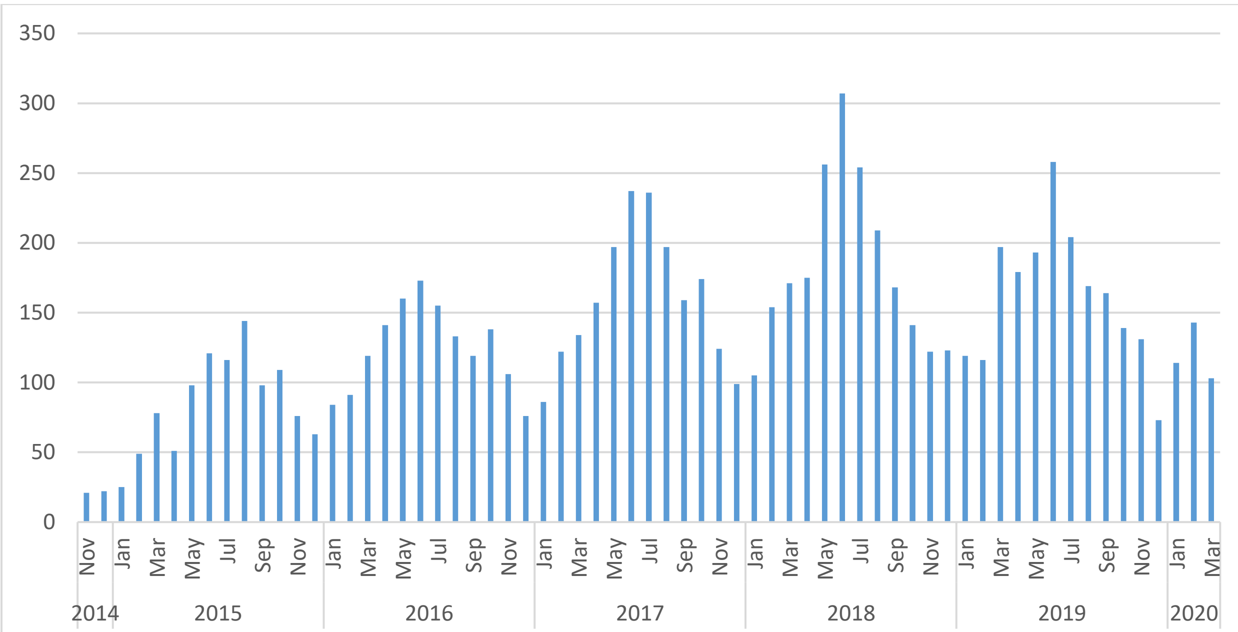


Figure 6: National sighting incidents over time.

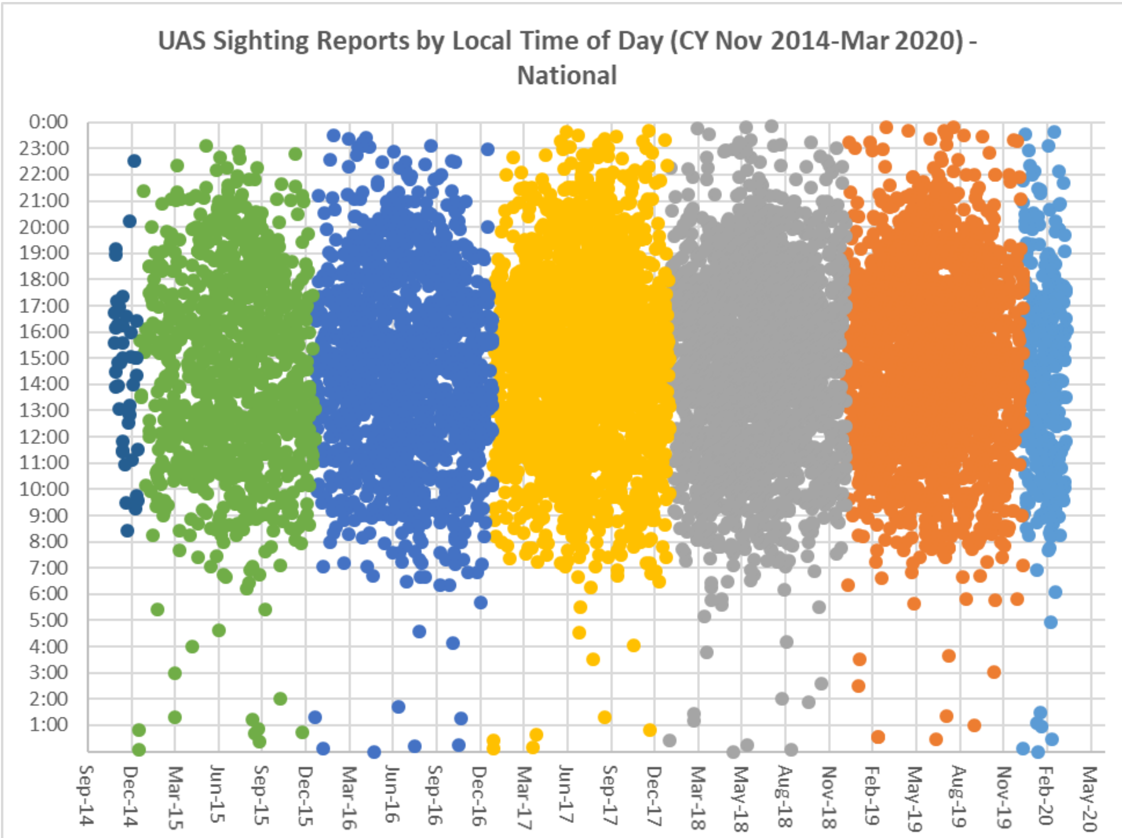


Figure 7: UAS Sighting Reports by Local Time of Day - National.

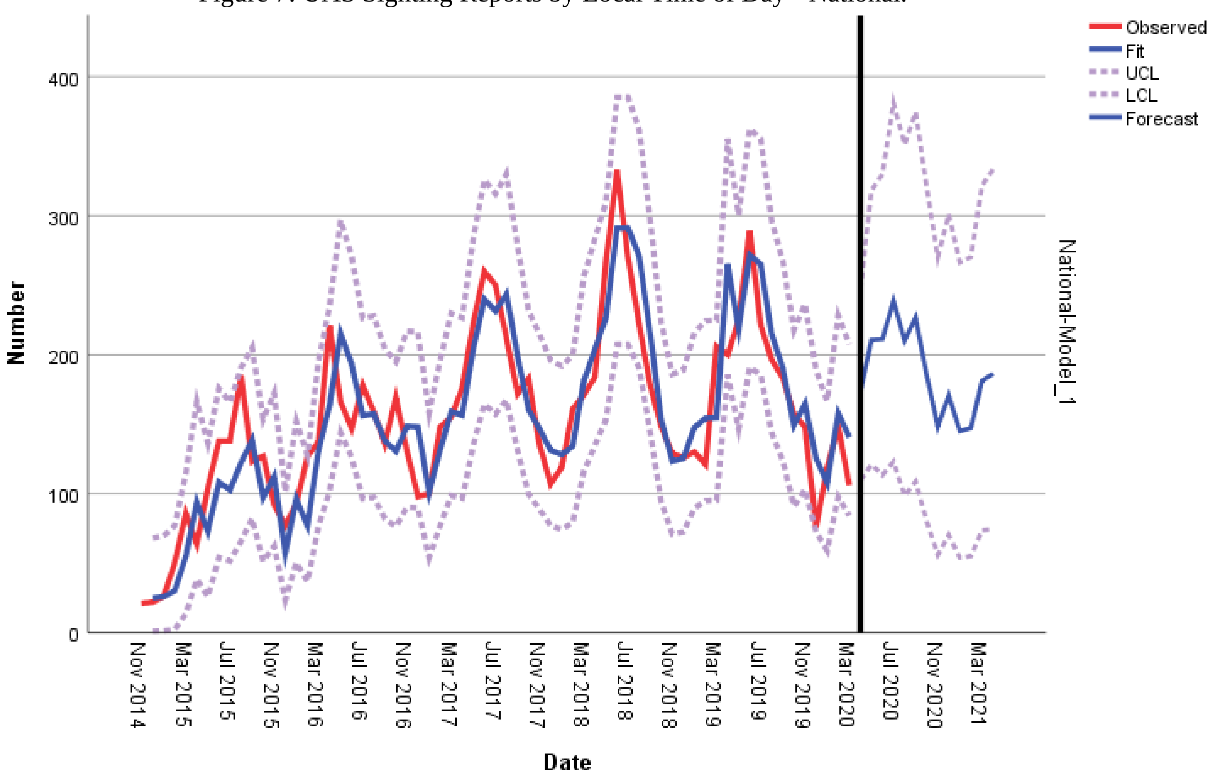


Figure 8. Sighting Incidents 12-Month Forecast – National.

2.3.3 Identified Data Set Gaps and Improvement Recommendations

Section 6.5 of Addendum 3 identifies gaps in the current data sets and improvements that can be made to mitigate those gaps.

UAS Registrations, Certificates, Waivers, and MLS operations. The main gaps in these analyses are the quality and format of the data. The lack of standardization limits the type of analysis that can be conducted, thus, limiting the findings. Following are the discussions of those gaps and recommendations for those data sets.

- Registration data: Part 107 registration variables can be further standardized to be usable for further analysis
- Certification data: Remote pilot certificate data do not differentiate initial certification from re-certification; therefore, the team cannot differentiate between initial certifications and total certifications issued for each month. Clarification could be added to the data set. Additionally, remote pilot certificate data on the FAA FOIA are only available by quarter. Certificate data by day could be provided.
- Waiver data: Waiver application data are available only as textual data from the FAA FOIA library in PDF format. The research team did not receive a complete data set of raw waiver applications with both accepted and rejected waivers, which limits the team's analysis. A data set of all applications could provide insight regarding the number of waivers by category requested and the success rate of waivers by category.
- There is no information regarding approved and denied requests. Several waiver applications cover multiple regulations, which require standardizing the data for further analysis. Additionally, address fields should be standardized and broken into individual elements to aid geospatial analysis, such as mapping results to a specific locality. Standardization of variables is recommended to allow further analysis.
- MLS data: For MLS operations, aircraft type and operation variables should be standardized for further analysis. For MLS incidents, only 55 incidents or accidents were reported from May 2015 to June 2019. The incident reporting system may need to be updated
- With more standardization for those data sets, they can be consolidated for further analysis. Appropriate multivariate statistical analyses could be conducted to examine the correlations among those variables and effects of specific events on the changes of registrations, certificates, or waivers.

UAS Sighting Reports. The team recommends the FAA address the recommendations provided by the GAO (2019):

- The FAA should identify UAS-specific education and training needs for inspectors and develop appropriate training to address any needs identified.
- The FAA should develop an approach to communicate key information more effectively to local law enforcement agencies regarding their expected role with regard to small UAS safety oversight.
- The FAA should identify existing or new data and information needed to evaluate oversight activities and develop a mechanism for capturing these data as needed.

The FAA should revisit the sighting report mechanism, identify necessary variables, and redevelop the reporting form. More checkboxes and/or radio buttons and multiple-choice questions should be used to improve the reliability and usability of the data through standardization. Text fields may still be used but only to identify and capture unique information that cannot be captured through standardized fields. Table 17 in Section 6.5 provides a specific set of recommendations for variables and a coding format to improve data collection of sighting data enabling greater use of quantitative analytics techniques.

2.4 Qualitative Analysis of Data Requirement Gaps for SMS Safety Risk Analysis

Within Task 1-3, a qualitative analysis of NPRMs, current SMS requirements, and the Part 107 waiver process identifies recommendations to improve future data collection practices. The improvements shall enable data-driven safety risk management of UAS operations.

Addendum 4: Technical Report – Waiver and NPRM Analysis serves as the complete technical report of this effort The technical report associated with this effort includes a waiver and NPRM analysis, which includes the following subtasks:

- Describe the FAA current SMS approach with more focus on the safety risk management (SRM) component.
- Analyze waiver trend analysis reports and NPRM documents to map the document content to SRM steps.
- Identify the gaps between current waiver applications and NPRM documents to and the SRM process.
- Analyze the waiver request data to determine the trend of waiver requests over time.
- Recommend content needed to meet the SRM steps.
- Recommend additional data for future data collection to meet the SRM requirements.

Task 1-2 broadly discussed the data requirements for UAS CONOPS., which included a discussion of SMS. This section probes directly into the question: "what data elements enable SRM for small UAS under the proposed NPRMs?"

This section summarizes the work reported in detail within Addendum 4.

2.4.1 Scope and Tasks

The SRM process describes the systematic application of management policies, procedures, and practices to the activities of communicating, consulting, establishing the context, and assessing, evaluating, treating, monitoring, and reviewing risk. When undertaken, this process provides assurances that the risks associated with the operation of the UAS have been managed to acceptable levels.

This task identifies and describes the FAA SMS approach focused on the SRM process. Five steps in SRM (system analysis, identify hazards, analyze safety risk, assess safety risk, control safety risk) are analyzed and mapped to Part 107 waiver applications and NPRMs to identify gaps in the application data requirements and the needs to support SRM. The results can support regulators and applicants to identify and mitigate all potential risks in future waiver review and operational planning.

The FAA provides information and guidance on air traffic policies and prescribes procedures for the planning, coordination, and services involving the operation of UAS in the NAS. The SRM process and its outcomes form part of the documented safety case necessary to obtain approvals for unmanned aircraft system operations.

Our fundamental research question is: What SMS processes govern the analysis of waiver applications and the data requirements to validate each?

2.4.2 Qualitative Analysis

The data set includes UAS SRM requirements, SMS process requirements, Part 107 waiver applications trend analysis reports, type of waiver operations, NPRMs, times of NPRM changes, and final rule. In particular, the following documents were used in this study:

1. Trend Analysis: Beyond Visual Line of Sight (107.31) Waiver
2. Trend Analysis: OOP Operations Over People (107.39(a)) Waiver
3. Trend Analysis: Night Operations (107.29) Waiver
4. FAA-2018-1084-0001- 14 CFR Part 48 7 CFR Part 48- External Marking Requirement for Small Unmanned Aircraft
5. FAA-2018-1086-0001- 14 CFR Part 107- Safe and Secure Operations of Small Unmanned Aircraft Systems
6. FAA-2018-1087-0001- 14 CFR Part 107- Operation of Small Unmanned Aircraft Systems Over People
7. FAA-2019-0364-0001- 14 CFR Part 107-Exception for Limited Recreational Operations of Unmanned Aircraft
8. FAA-2019-1100-0001- 14 CFR Parts 1, 47, 48, 89, 91, and 107- Remote Identification of Unmanned Aircraft Systems

Utilizing a qualitative analysis tool called NVIO, the team identified nodes and node relationships to aid the analysis of the SMS specifications. These node hierarchies were built upon the FAA's SRM process including nodes for (a) system analysis, (b) Identify hazards, (c) analyze safety risk, (d) assess safety risk, and (e) control safety risk. Table 19 presents a detailed parent/child node hierarchy. Using the node hierarchy, the relevant sections of each document are linked within the tool identifying the inter-relationship of each document to one another for each of the nodes.

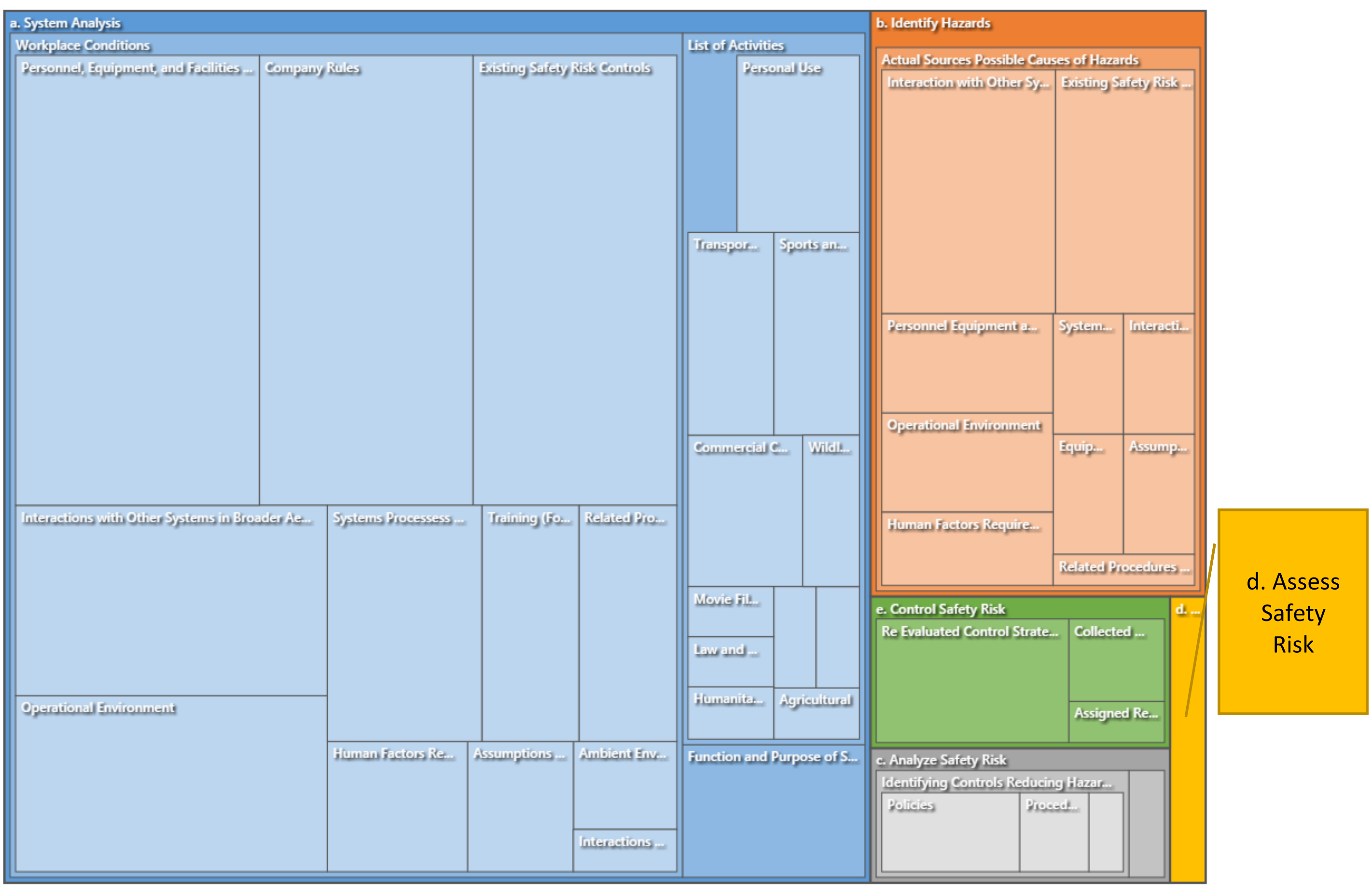


Figure 9.Hierarchy Chart.

The team followed an interactive coding procedure to review each document,; the researchers highlighted related sentences and paragraphs in the document and linked them to nodes in the hierarchy. Using a UAS SME, the research team repeated the analysis until reaching a desired interrater-reliability.

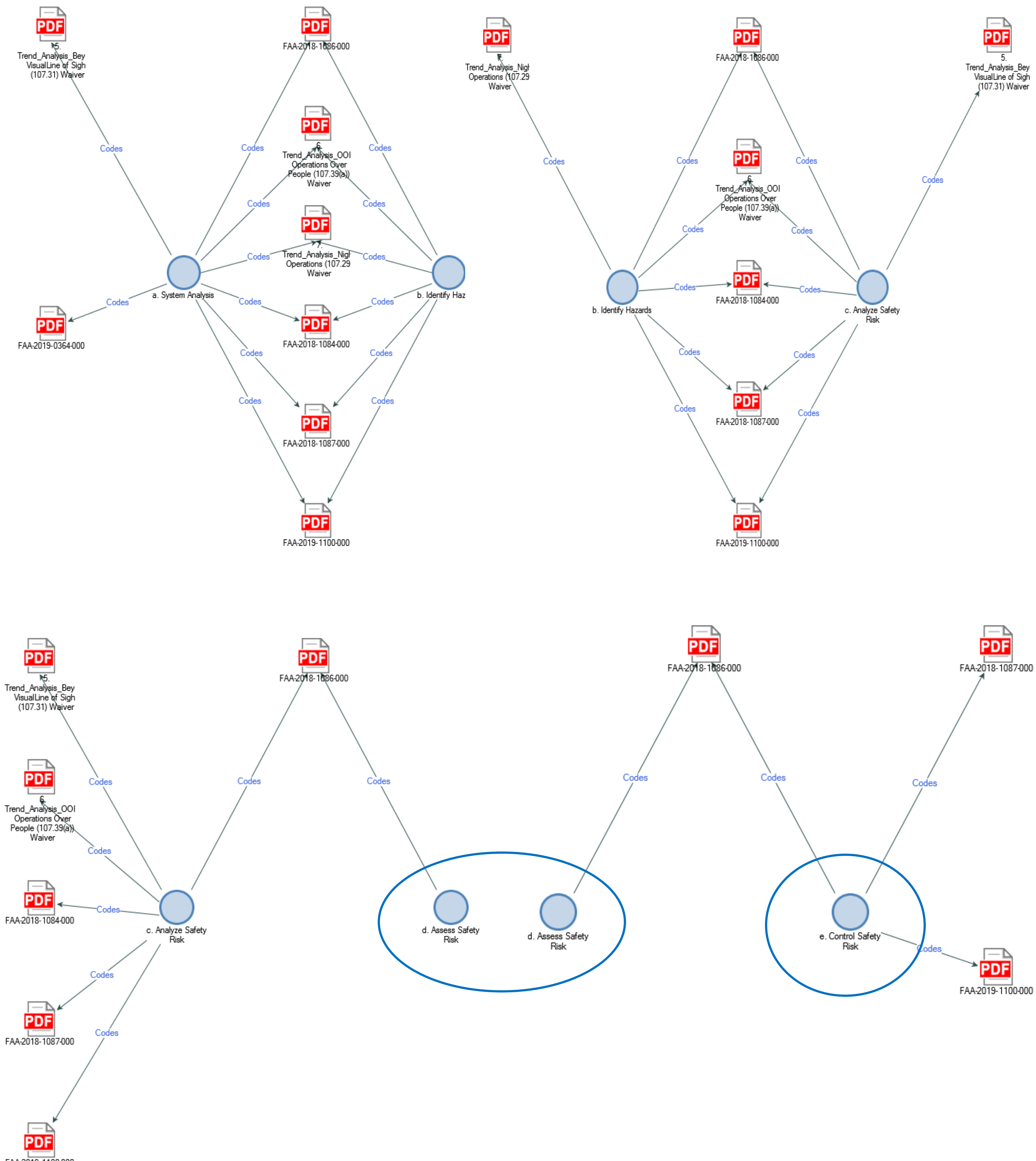


Figure 10: Comparison Diagram from NVIO linking node hierarchy elements to source documents.

Following the coding process, using NVIO the team analysis includes the generation of word clouds for each document, a tree map breaks down the relative frequency of the top-100 words within the documents, and a hierarchy chart (Figure 9) reveals for each node of the node hierarchy the relative size (number of linked items) for each, which reveals where guidance is abundant and where it is not. Figure 10 shows a comparison diagram in which the documents are compared with the high-level nodes of the node hierarchy to determine which documents sufficiently address the subject and which do not. The analysis reveals that the current processes and materials reviewed do not sufficiently address the data requirements associated with the "Assess Safety Risk" and "Control Safety Risk" for current and NPRM enabled operations.

The analysis revealed that insufficient detail and guidance exists for current and NPRM covered operations across SRM subtasks (c) analyze safety risk, (d) analyze safety risk, and (e) control safety risk. Risk levels must be clearly defined to enable analysis of the safety risks.

2.4.3 Recommendations

The research team provides a detailed set of recommendations in Section 7.6 (in Addendum 3), which are highlighted here to address the two key gaps identified with "Assess Safety Risk" and "Control Safety Risk." Additionally, the research team provides recommendations to improve the safety risk criteria utilized by the SRM process.

Proposed Improvements to Address Gaps of "Assess Safety Risk" and "Control Safety Risk." The research team provides recommendations to address the gaps in guidance for the SRM process. The process seeks to maintain a sufficiently safe level of operation throughout the lifecycle of the aircraft. The team recommends that risk management processes be developed and integrated into UAS rules and guidance materials including:

- A commonly agreed upon risk criteria framework for UAS operations defined for judging the acceptability of risk
- A procedure to prioritize identified hazards for risk mitigation actions
- A procedure for periodic review of existing risk mitigation records
- A procedure to account for mitigation actions whenever unacceptable risk levels are identified
- A program for systematic and progressive review of all UAS safety-related operations, processes, facilities, and equipment subject to the hazard identification and risk mitigation (HIRM) process as identified by the organization (ICAO, 2013)

Proposed Improvements to Address "Safety Risk Criteria." The risks associated with a given UAS operation can be defined by characterizing them into two broad categories: (a) ground risks; and (b) air risks. The risk criteria framework for UAS operations can be established to judge the acceptability of risk. The research team provides some recommendations on safety risk management and their respective criteria including potential assessment processes, a notional risk matrix for assessing risk of a proposed operation given likelihood and severity of a hazard, and a clear definition of likelihood and impact categories.

2.5 Visual Sightings Database Validation

A 2018 National Academies of Science report discussed recommendations for data-driven risk assessment and associated challenges. Its authors acknowledge that "Accepting risk is far easier when the risk is well quantified by relevant empirical data" (National Academy of Science, 2018, p. 41). However, gaps exist with respect to UAS encounter statistics and operational characteristics of UAS at lower altitudes.

Addendum 5: Technical Report – Visual Sightings Database Validation" presents the research conducted as part of Tasks 1-4 of this project. Researchers sought to evaluate UAS user activity within the NAS using

UAS detection technologies and evaluating the accuracy of UAS sighting reports by integrating detected UAS flight track information with manned aircraft flight tracks.

The research team sought to answer the following questions:

- Is there a relationship between the quantity of UAS sighting reports, registered UAS population, and drone detection census?
- Where are UAS operations taking place?
    - Airspace
    - Altitude
    - Launch locations
    - Proximity to Aerodromes, Approach
- Are UAS operations compliant with existing regulations?
    - Altitude limits
    - LAANC authorizations
    - Line of sight?
- Are pilot sighting reports of unmanned aircraft a valid measure of UAS-aircraft NMAC risk?
- To what extent do close encounters between aircraft and UAS occur that are not reported?

To achieve this goal, the team shall leverage the DJI AeroScope to capture real-time UAS flight status, telemetry, and other information of DJI-brand UAS through continuous, passive monitoring up to 50km (DJI, 2020). DJI UAS platforms make up approximately 77% of the U.S. UAS sales, commanding a market share nearly 20 times larger than its closest competitor (Schmidt & Vance, 2020).

A G-18 Aeroscope device located at Dallas-Fort Worth International Airport, Texas, collected data from 15:30 (ET) 22 August 2018 to 23:00 (ET) 31 January 2020. Data collection was continuous with only minimal disruptions. The research team analyzed the data set, which the team received through an industry partnership. Of the detected 12,520 unique unmanned aircraft, three model types dominated the data set, including the MavicPro (31.0%), Mavic 2 (25.5%), and MavicAir (10.8%). Approximately 9.8% of the detected unmanned aircraft were unable to be identified. The number of UAS flights strongly correlated (r = .96) with UAS model population (see Figure 92).

2.5.1 Operational Findings

From the analysis of the UAS detection data, visualizations of operational findings are presented in Section 8.4.2 within Addendum 5. The team analyzed operations by time of operation, day of year, flight duration, flight altitude, proximity to aerodromes, comparison with registration data, and a summary of growth trends.

Time of Day. All data within the data set contained detection time information. The mean time of detected UAS flights occurred at 13:58 (CT) and at a median time of 14:16 (CT). On both An elevated number of flights were detected on both Saturdays and Sundays in the mid to late afternoon hours (see Figure 93). Most flights occur within daylight hours, but the team assessed the flights with respect to Part107.29 provisions. Sunrise, sunset, and civil twilight times were graphically plotted and overlaid with UAS detections for the 2019 portion of the data set (see Figure 94).

Day of Year. The team counted the number of daily UAS detections for each day within the observation period. Peak operational dates reflect disproportionately higher levels of detected UAS activity. Several peak operational dates corresponded with recognized holidays, which suggest elevated hobbyist activity (see Table 23). Dates with depressed UAS activity levels were also identified (see Table 24).

Flight Duration. The duration of detected flights tended to be extremely short, with a mean of 76 seconds and a median of 18 seconds. Notably, among the 162,162 flights, 59,006 observed flights had durations of 0 seconds—these have been removed from the data set for analysis purposes. Figure 96 plots a histogram of the number of flights reported by mission duration. The analysis also revealed that the Phantom 4, Inspire 2, and Mavic Pro flew longer flight duration totals in comparison to other UAS platforms.

Altitude. Approximately 94.7% (*n* = 153,535) of all detected UAS flights occurred below 400 ft AGL. Researchers noted 4,735 UAS flights exceeded 500 feet AGL, with 1,168 of those exceeding 1,000 ft AGL. Figure 99 plots the distribution of UAS flight altitudes within the detection data set. Figure 96 plots on a map of the vicinity of DFW the location of detected flights operating in excess of 1,000 ft AGL. While the data set shows that most operators adhere to altitude restrictions, a small portion of the data set indicated gross non-compliance, with three flight detections from three separate DJI MavicPro operators exceeding 21,000 feet AGL.

Proximity to Aerodromes. Using geolocation information, the research team assessed each flight's proximity to area airports. DFW encountered 226 UAS flights within 0.5 NM of the airfield, with some flights actually occurring on the airfield. Grand Prairie Municipal (GPM) encountered eight flights within 0.5 NM of the field (see Figure 101). Without additional LAANC or airspace approval data, the researchers are unable to determine if these flights were authorized. The research team also assessed UAS flight proximity to known heliports. The team assessed operations in the vicinity of fifty-one heliports in the Dallas-Fort Worth area sample (see Figure 101Figure 99). A total of 10,919 UAS flights flew within 0.5 NM of heliports during the sampling period (see Figure 104).

Registration Data. Of the complete data set, 99.4% of the platforms (*n* = 12,444) contained geolocation information. The research team assigned each detected platform to a zip code, based on its first detection location. Researchers tallied detected UAS platforms based on assigned zip code and compared them against total number of registrations for each zip code contained in the FAA's UAS Registration Database [2019Q4 release]. The FAA registration database contained 28,885 platforms for all applicable zip codes, including 7,734 registered under Part 107 and 21,151 UAS registered for hobbyist or recreational use. Given these data, AeroScope detections for the area accounted for up to 43.1% of all registered unmanned aircraft in the area. The number of unique platforms detected in some areas exceeded number of FAA registrations in the area, which may indicate that not all UAS are registered by their users. Alternatively, users may be flying their UAS outside their respective registration area.

Growth Trends. Using the historical detection data, the research team attempted to project future industry growth patterns. The research team evaluated the data set for initial detections of new UAS serial numbers, a possible growth indicator. Similarly, the research team assessed the data set for UAS serial numbers which were no longer active, a possible consolidation indicator. The results are presented in Figure 106. Over the 18-month sampling period, the data shows a marked decline in new entrants and an accelerating rate of platforms no longer in active use. September 2018 showed a net gain of 659 platforms, while December 2019 showed a net loss of 302 platforms. These results only reflect observations made in the DFW region, which may not necessarily represent UAS operational activity in other areas of the country.

In a separate analysis, the research team counted the number of total flights flown by UAS serial number (see Figure 109). At least 45.5% of UAS (*n* = 5,696) were *only flown five times.* Nearly 83.5% of platforms (*n* = 10,451) had performed *less than 20 flights* until they were no longer actively detected. The researchers believe this finding may suggest that the majority of UAS are operated at a high frequency for a short span of time, and likely for hobbyist or recreational purposes. Once the novelty of the platform has worn off, operators relegate the UAS to storage and only rarely fly again.

2.5.2 UAS Sighting Report Analysis

The research team conducted an in-depth analysis of UAS sightings by pilots, controllers and other stakeholders that occurred within the vicinity of Dallas-Fort Worth International Airport and were reported to the Federal Aviation Administration. The sample included 41 reports of UAS encounters or other potentially hazardous UAS activity that occurred between 3 December, 2018 and 15 August, 2019. In most cases, the sighting reports could not be positively validated for the following reasons:

- No UAS was detected in the vicinity of the reported UAS sighting location
- Sighting report location was out of range of the DJI Aeroscope sensor or available TFMS telemetry data
- UAS sighting report narrative did not provide adequate detail to pinpoint position of UAS
- Multiple, simultaneous UAS operations were detected that could have met the sighting criteria

The results of this analysis are presented in Section 8.4 of Addendum 5: Technical Report – Visual Sightings Database Validation. The researchers assumed that the documented sighting reports included generally accurate time and position information for sighting events. The detection system detects DJI-manufactured UAS only, which limits the researchers' ability to correlate sighting reports caused by a non-DJI UAS. Sighting reports are generally considered error prone because of the difficulty pilots experience in accurately approximating the range of a UAS-sized aircraft. Sighting reports also do not necessarily involve a violation of safety criteria and authorizations. Lastly, the manned traffic data extracted from the FAA's Traffic Flow Management System provides a relatively low sample rate for aircraft position updates, which reduces the fidelity of the geolocation analysis between the reporting vehicle (if correlated) and detected UAS.

Of the analyzed sighting reports, researchers correlated 50% to UAS detection data, but 25% could not be correlated due to a lack of UAS detection data in the sighting area and 25% could not be correlated because the sighting location fell outside of the Aeroscope coverage area. Figure 11 illustrates the visualization of UAS detection data and manned aircraft flight track data correlated to a sighting report.

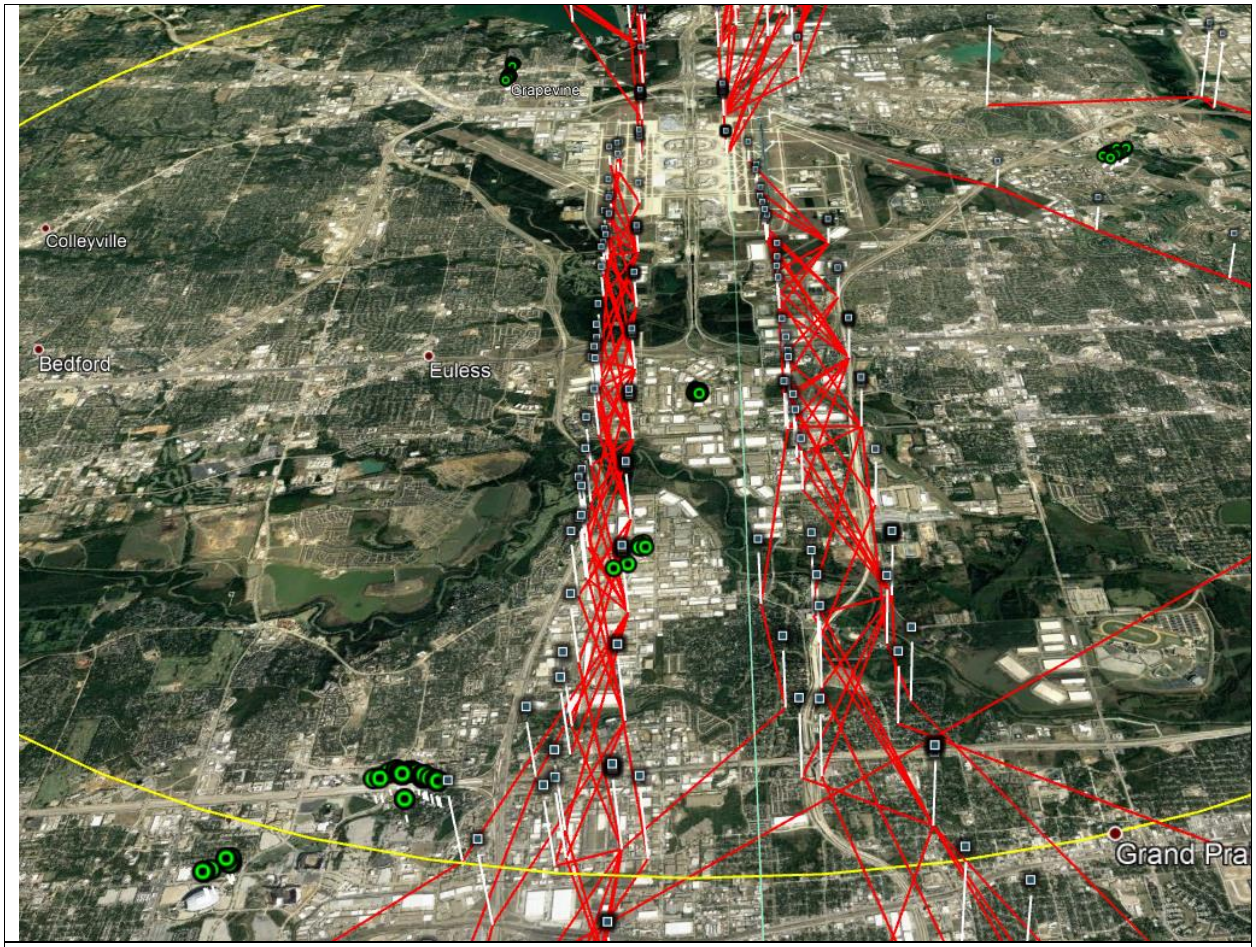
2.5.3 Observations

These data may suggest the following conditions:

- Smaller-sized UAS seem to be preferred, which are likely to be difficult to spot by pilots
- Operations data indicates there may be sizable pockets of unregistered UAS in select areas
- Gradually declining number of actively operating UAS platforms
- Most UAS operations remain clear of airports, but may be inadvertently operating near private heliports
- Generally compliant operations, with a small number of outliers that may pose elevated hazards to aviation
- High levels of recreational platform use; generally, these platforms see only high frequency initial use

For sightings data, the team found correlation of a sighting report to a specific manned aircraft and UAS within the telemetry data set challenging, but followed a methodology that ensured correlated flights met all factual criteria that could be validated within the data set. The research team observed that in many cases, pilot estimations of distance and altitude to UAS were much closer than the data indicated. Most correlated sightings fall within below 400 feet and represent non-hazardous UAS activity. However, a greater understanding of compliance with operational limits could be achieved through a comparison of local LAANC grid limits and data on LAANC authorizations for operations within the airspace.

While not all reported UAS sightings were validated by the research team, the established methodology shows promise toward leveraging empirical data to analyze UAS sighting reports. For future analysis, the research team recommends the use of aircraft traffic data with higher temporal and spatial resolution, such as ADS-B.



PRELIM INFO FROM FAA OPS: DALLAS-FORT WORTH, TX/UAS INCIDENT/1232C/DFW ATCT ADVISED A321, REPORTED A WHITE QUAD COPTER 200 FEET BELOW ACFT WHILE ON VISUAL APPROACH TO RUNWAY 35C 8 S DFW. NO EVASIVE ACTION REPORTED. DFW DPS NOTIFIED.

UAS MOR Alert for D10
Number: D10-M-2019/05/12-0004
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: May 12, 2019 - 1732Z
A/C: (A321)

Summary: A321 on a visual approach to DFW RWY 35C reported a white quad copter 8 miles south of the airport 200 feet below them. A321 did not take any evasive action.

Figure 11. Sample UAS sighting report telemetry and accompanying sighting report (correlated). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. In this case, multiple UAS activities were occurring along the approach path, with a maximum altitude of approximately 149m (488 ft AGL).

3 Conclusion

This section summarizes Phase 1's key research findings including recommendations for data collection and analysis improvements. Based on the findings, the team highlights follow-on research opportunities.

3.1 Summary of Key Findings/Recommendations

This section summarizes the key findings and recommendations of Phase 1.

Data Set Assessment. Numerous UAS data sets have been acquired from multiple sources (e.g., public websites, the FAA, private sources). To understand the breadth and types of UAS data, the research team developed a data catalog. This catalog provides data categories, types of data provided by data sets, and information regarding data acquisition. Some data sets are being utilized to predict trends associated with UAS. Those data have and are being analyzed to understand data characteristics, include completeness, presence of non-physical/errant entries, and data inconsistencies. Key findings and recommendations from this task include:

- Research of waiver data was limited to only approval letters. Summary data provided by the FAA sponsor within the report summarizes the categories of UAS waiver submitted and their acceptance rate.
- A mechanism should be developed to facilitate the exchange of data within the FAA across organizational boundaries and in consideration of constraints upon data (e.g., potentially proprietary information within the waiver data set).
- Data collection improvements are provided for the MLS data set to reduce the number of invalid (incomplete or non-physical entities) and standardize data fields.
- Waiver data provided in PDF format permitted some automated data extraction, but some inconsistencies in formatting required manual data processing. Storage of data as text in tabular format recommended.

Data Needs for UAS CONOPS Evaluation. To understand UAS CONOPS, the team leveraged results from other ASSURE efforts—A2 and A18. This provides tremendous detail regarding a variety of CONOPS and provides a high-level summary of CONOPS for BVLOS, operations over people, and operations over moving vehicles. This breakdown could further be simplified according to air risk and ground risk. Each of these categories contains many CONOPS. Moreover, CONOPS often will involve more than one of these categories.

- Waivers for BVLOS frequently utilized VOs, but few utilized DAA systems, which illustrates that broad access/adoption of suitable DAA technologies still poses a barrier to enabling BVLOS operations.
- Operations over people are becoming more common, as waivers that are enabled through the use of parachutes (and, commonly, height restrictions) are being successfully obtained.
- Analysis of rejected Part 107 waivers indicate that these generally fail, owing to a lack of information critical to development of a safety case: operational context and system performance (especially safety mitigations).
- Agreed upon metrics and performance requirements could enable a greater rate of successful waiver applications UAS operations.
- Existing data sets identified to enable CONOPS evaluation include MLS, UAS safety cases, Aviation Safety Information Analysis and Sharing (ASIAS) for UAS, and historical operational data such as UAS sighting data, detection data, registrations, and the like to evaluate NAS risk.
- Two ASSURE efforts, A19 and A20, are developing systems for collection of both test and operational data. These efforts are expected to enhance not only collection of data regarding UAS CONOPS, but also evaluation of progress regarding CONOPS (including aggregated data) and

needs for further research. It is expected, then, that the efforts herein and in related efforts will accelerate realization of UAS CONOPS.

- Fundamental data needs for CONOPS evaluation include:
  - Clear definition of the operational context (including system limitations)
  - Defined metrics and performance requirements
  - Test data that illustrate conformance with performance requirements/expectations within the operational context

Quantitative Data Analysis. The research team performed quantitative analysis to explore, evaluate, and identify trends of the data collected within the data catalog. Data preparation including cleanup and pre-processing aided the analysis, but some issues with the existing data collection processes and formats were noted. These issues limit the ability to exploit data collected due to the suitability of the format, completeness of the data set, the temporal resolution of data (monthly versus quarterly aggregates, etc.).

The report summarizes the analysis of the data catalog, primarily collected between 2015 – 2020. Beyond illustrating trends in current UAS operations and data collection practices, the team identifies opportunities for improvement. A few noteworthy observations include:

- Observations by data set include:
  - **Registration Data**. Part 107 registration variables can be further standardized to be usable for further analysis.
  - **Certification data.** Remote pilot certificate data do not differentiate initial certification from re-certification. Data aggregated by date instead of month would be provided enabling further trend analysis.
  - **Waiver data.** Limited access to only accepted waivers constrained the analysis the team performed as discussed under Section 4.5's research conclusions. Recommendations based on the data needs for SRM are discussed in Section 7.6.
  - **MLS data.** MLS reports FAA UAS test site operations and incidents/accidents.
    - Operational data collection practices must be improved to ensuring standardization of data formats.
    - 55 incidents or accidents were reported from May 2015 to June 2019.
  - **Sightings Data.** As observed in Task 1-3 and Task 1-4, the mechanism for reporting UAS sightings must be improved to enable future quantitative analysis of such events.
    - The team recommends the FAA revisit the reporting mechanism for UAS sightings, identify all necessary variables, and redevelop the reporting form to improve completeness and consistency.
- An examination of UAS sighting data both nationally and divided between NOAA climate regions revealed sufficient regional variability to have a significant impact on forecasts of future trends.
- Standardization of data fields across data sets would improve quantitative analysis opportunities.
  - Inconsistent data formats limit the breadth of analysis achievable especially when free-form text fields are utilized such as sighting incident and waiver data.
  - Specifically, the team observed that standardization of data fields and data entry methods to construct each could enable the data to be consolidated for further analysis.
  - For instance, appropriate multivariate statistical analyses could be conducted to examine the correlations among those variables and effects of specific events on the changes of registrations, certificates, or waivers.
- The team noted that the GAO (2019) has recommended the FAA improve its data and communication. Specifically, the GAO recommended:
  - The FAA should identify UAS-specific education and training needs for inspectors and develop appropriate training to address any needs identified.

  - The FAA should develop an approach to communicate key information more effectively to local law enforcement agencies regarding their expected role with regard to small UAS safety oversight.
  - The FAA should identify existing or new data and information needed to evaluate oversight activities and develop a mechanism for capturing these data as needed.

Qualitative Analysis of Data Requirement Gaps of NPRM/SMS Processes. Qualitative analysis through the development of a node hierarchy, coding the FAA waiver application, SMS guidance materials, and NPRMs identified shortfalls in current SMS processes and data collection practices; particularly, SRM gaps were identified. Observations for research Task 1-3b include:

- Analysis of SRM Process documents, waiver requests, and NPRMS revealed documents sufficiently cover the first three steps of SRM (system analysis, identify hazards, and analyze safety risk) sufficiently, but fail to address sufficiently the remaining two steps (assess safety risk and control safety risk).
- To enable safety risk assessment and mitigation as part of SRM for UAS, a new process must be developed that addresses:
  - A commonly agreed risk criteria framework for UAS operations defined for judging the acceptability of risk.
  - A procedure to prioritize identified hazards for risk mitigation actions.
  - A procedure for periodic review of existing risk mitigation records.
  - A procedure to account for mitigation actions whenever unacceptable risk levels are identified.
  - A program for systematic and progressive review of all UAS safety-related operations, processes, facilities, and equipment subject to the hazard identification and risk mitigation (HIRM) process as identified by the organization (ICAO, 2013).
- Risk assessment criteria needs to be adopted that leverages risk assessment of air-based and ground-based risk for different risk acceptance or safety compliance levels based upon operation type (e.g., operator compliance for Part 107 operators, industry-level compliance for waivers, exemptions, etc., and FAA-level compliance for type-certified UAS).

Validating UAS Sighting Reports with UAS Detection Data. An analysis of UAS sighting data leveraging UAS detection data collected in the vicinity of Dallas-Fort Worth Airport over an 18-month period (August 2018 – January 2020) provided a census of 12,520 unique DJI sUAS across more than 162,000 separate operations. Operational findings from Task 1-4 include:

- Data suggests high levels of UAS utilization, primarily during daylight hours, with slightly elevated levels on weekends.
- Generally, flight activity remained stable throughout the year, with spikes during selected holidays and weekends, and troughs at the beginning of the calendar year and selected weekdays.
- Flight operations reveal strong preference of users for modern UAS platforms including the Mavic Pro, Mavic 2, and Mavic Air.
- Analysis of UAS detections near DFW may suggest the following conditions:
  - Preferred platforms are generally smaller in size, which are likely to be difficult to spot by pilots
  - Operations data indicates there may be sizable pockets of unregistered UAS in select areas
  - Gradually declining number of actively operating UAS platforms
  - Most UAS operations remain clear of airports, but may be inadvertently operating near private heliports
  - Generally compliant operations, with a small number of outliers that may pose elevated hazards to aviation

  - High levels of recreational platform use; generally, these platforms see only high frequency initial use
- Issues encountered with validating sighting reports were identified. In most cases, sighting reports could not be positively validated for the following reasons:
  - No UAS was detected in the vicinity of the reported UAS sighting location
  - Sighting report location was out of range of the DJI Aeroscope sensor or available TFMS telemetry data
  - UAS sighting report narrative did not provide adequate detail to pinpoint position of UAS
  - Multiple, simultaneous UAS operations were detected that could have met the sighting criteria

Utilizing the detection data, the research team developed and piloted a methodology to correlate UAS sighting reports with manned and unmanned telemetry-based flight paths to assess the validity of the reported event. The research team observed:

- In many cases, pilot estimations of distance and altitude to UAS were much closer than the data indicated.
- This phenomenon seems to support previous UAS visibility study research by Loffi, Wallace, Jacob, and Dunlap (2016) that indicated relatively poor accuracy with regard to pilot estimations of distance to converging UAS.
- The vast majority of these correlated sightings represent merely aircraft observations of non-hazardous UAS activity. Most detected the UAS operating at altitudes below 400 feet AGL.
- For sightings data that was able to be correlated to telemetry, most incidents do not generally present indications of serious aviation hazards. Most sightings were for UAS operating at low altitude below 400 feet AGL.
- While the research team was unable to validate all reported UAS sightings, the established methodology shows promise as means of leveraging empirical data to analyze UAS sighting reports.
- Future analysis should consider utilizing flight track data for manned aircraft with a faster temporal resolution (update rate) than the TFMS data set used.

Lastly, the research team recommends that the FAA and ASSURE coalition work together to improve the exchange of data for research purposes. The FAA did not fulfill two data requests within the period of performance for Phase 1 of the A21 project. A data set of LAANC authorizations that included the time of request, aircraft identifier, and control station/pilot location would enable UAS detection data to be correlated to LAANC waivers to better assess compliance of operations to authorizations. Raw FAA waiver data was not provided as requested by the team, which prevents analysis illustrative of the demand of UAS waivers by type and the success rate of waiver applications by type. The FAA also failed to provide manned aircraft flight tracks in areas surrounding UAS sighting data in time to complete analysis of UAS detection and sighting data in the vicinity of UAS sighting report locations, which limited the researchers scope of the "Visual Sightings Database Validation" task.

3.2 Applicability of Findings and Future Work

The team's analysis provides a unique glimpse into the status of UAS integration into the NAS informing policymakers regarding the impact of past and ongoing UAS integration efforts by the FAA and its partners. These results shall provide guidance toward this project's Phase 2 efforts in developing a forecast model to predict the future demand for UAS operations and Phase 3's effort to develop a probabilistic risk assessment framework to evaluate the safety of new concepts of operations.

The team recommends the following future research opportunities:

- Collaboration with the FAA to establish new UAS data standards.
- Study the impact of climate, weather, time of day, and time of year on UAS data trends to inform localized forecast models of demand for future UAS operations.

- Identify data collection and analysis practices for data deemed sensitive due to concerns related to security, confidentiality, and privacy.
- Identify and recommend specific data collection improvements and analysis techniques to enable the FAA's safety risk management process for new and upcoming UAS operational capabilities.
- Conduct a broader (i.e., sites nationwide) UAS detection study to census UAS operations across a variety of operating environments characterizing the operations within the environment, evaluating compliance of UAS operations with UAS rules, and correlate with flight tracking data from other airspace users.

4 Addendum 1: Technical Report – Data Set Assessment

4.1 Introduction

Task 1-1 of A21 seeks to identify, acquire, and analyze data sets that provide insights into expanded and integrated UAS operations. The research team acquired UAS data sets from multiple sources and developed a data catalog to develop an understanding of available data types, categories, and uses. The team analyzed the data to understand data characteristics to include completeness, presence of non-physical/errant entries, and data inconsistencies.

The subtasks associated with Task 1-1 are:

1. Develop master list of data sets.
2. Document the formats associated with the data sets.
3. Document data elements associated with the data sets.
4. Determine utility of data sets by relating to data elements that are identified by the team as being needed for the analysis.
5. Develop a plan for accessing data sets, including multiple approaches when possible to maximize the likelihood of timely reception of the data.
6. Determine applicable restrictions (proprietary, IRB, etc.).
7. Characterize the data sets (descriptive statistics) and produce a data catalog.
8. Acquire data by coordinating with the data collection team.

4.2 Data Catalog

The A21 team developed a data catalog to describe data sets. In developing this catalog, the organizational structure utilized in Ahmed et al. (2017) was emulated. Thus, the data catalog, which is maintained as a Microsoft™ Excel™ workbook, is organized into the following sections:

- Registration: Data providing information regarding Unmanned Aircraft (UA), pilots, and locations
- Intent: Data elements describing intended uses of UA
- Platforms and Models: Provides information regarding UA
- Company-Level Data: Information regarding manufacturers of UAS and UAS components
- Tracking and Trajectory: Information regarding flight tracks and trajectories
- Safety: Data related to safety of UAS operations

The Microsoft™ Excel™ workbook is organized into sheets. The first sheet provides information regarding data sets that have been acquired by the A21 team. The other sheets provide information regarding data sets that belong to the categories listed above (each category has its own sheet). Within a data category sheet, information regarding data types is provided, along with information regarding data ownership, acquisition, and comments. An example is provided in Table 4 with a digital copy of the spreadsheet accompanying this report.

Table 4. Example of a data category sheet from the A21 data catalog.

Data Elements	***Comment on Data Element***	***Remote Pilot sUAS Airman Certification Database***	***sUAS Registration Service***	***Legacy Aircraft Registration Master File (AC Form 8050-1)***
Manufacturer / Model	**Collision Risk Severity**		X	X
Aircraft Size				
sUAS-Weight				X
sUAS-Group				
sUAS-Type (quadcopter, etc.)				X
Type of operation (107, 135, COA, etc.)				
Airspace	**Collision Risk Likelihood**			
Location				
Time of day				
Altitudes				
Use Case				
LAANC authorization used (Y/N)				
Type of Waiver				
Number of UAS Registrations			X	
Registration Location (City, State, county, zip)		X	X	X
Waiver company name				
Waiver expiration date				
Responsible Person		X	X	X

Waivered Regulation				
Mission				X
Associated CONOP				
UAS Sighting: Date/Time				
UAS Sighting: Location				
Accident/Incident Info				
Callsign	Data elements on manned traffic to evaluate with respect to historic airspace utilization.			
Flight Track (actual) - lat, long, alt				
Flight Plan (filed)				
Departure Airport				
Arrival Airport				
ICAO Identifier				
Aircraft category				
Horizontal Velocity				
Climb Rate				
Mitigating Methods	Methods to address risk (parachute, blade guards, etc.).			

Comments on Data Sources		FAA Only accessible by FAA and FAA contractors maintaining the system. FAA and FAA contractors must comply with strict legal requirements to protect confidentiality of personal data.	FAA Full data can only be accessed by the FAA and FAA contractors that maintain the website and database.	FAA Only publicly available registration data including names and addresses of UA owners. To extract the set of UAS aircraft, the CSV files must be filtered on the number of seats (zero) and the aircraft type (4, single-engine fixed-wing; 5, multi-engine fixed-wing; 6, rotorcraft).
Access to Data		Office of Unmanned Aircraft Systems Integration (AUS-400).	AUS-400 (Safety and Integration Division). https://www.faa.gov/foia/electronic_reading_room/media/Reg-by-City-State-Zip-14Feb2017.xlsx Data file provided by FAA on 4 November 2019.	Aircraft Registration Branch (AFS-750). https://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/releasable_aircraft_download/ http://registry.faa.gov/aircraftinquiry/

Other Comments		Commercial operators only.	All UAS weighing >0.55 lbs. and < 55 lbs. Commercially operated aircraft are registered individually. Other owners receive a single registration number for all UAS they own. Publicly available data include limited data regarding registration counts by location. Publicly available data do not include information regarding UAS type or activity. Addresses do not directly correspond to exact locations of flights.	Once the Part 107 process came online, utilization of this likely declined significantly.

4.3 Data Acquisition

Data have been acquired through multiple means. Some data are publicly available and, thus, have been downloaded from their repositories. Other data were provided to the A21 team by the FAA relatively early in the project to help the A21 team with its tasks. Additional data have been acquired by the A21 team through data requests that were submitted to the FAA. Owing to data restrictions (propriety data, etc.), some data requests were rejected by the FAA. The A21 team continues to work with the FAA to acquire data that enables completion of its tasks. Finally, some data were obtained through agreements developed by individual performers in A21. An example of this type of data is UAS detection data, which were acquired by ERAU. A summary of the acquired data sets is provided in Table 5.

4.4 Data Characteristics

Characteristics of the data, such as completeness, presence on of non-physical values, consistency, etc., affect their utility. The A21 team has analyzed data characteristics for several data sets that have been collected. It is noted that this analysis has not been performed for every data set since doing so would be prohibitive. These analyses have been performed for data sets that are being used to predict trends, etc. As new data sets are utilized, characteristics associated with those data sets will be produced.

4.4.1 UAS Sightings Data

These data provide date/time, location, and additional information (e.g., estimated altitudes) regarding UAS that were observed near airports and aircraft. These data are being analyzed by the A21 team to identify trends. To support that analysis, these data have been sorted by month and by climatological region (NOAA 2020; National Oceanic and Atmospheric Administration). During this analysis, this data set was determined to be very complete. Only a few records were rejected owing to either a lack of location or description.

4.4.2 Approved Part 107 Waivers

Approved Part 107 waivers through 18 April 2020 (data spans 15 June 2016 to 18 April 2020) were harvested from the FAA Part 107 website. These waivers were analyzed to identify mitigations that enabled operations and restrictions imposed upon the operations.

Approved Part 107 waivers are provided in the form of .PDF files. Analysis of these data was enabled by developing algorithms that extracted desired information from these waivers. This is possible because Part 107 waivers are structured in a systematic way. However, differences in waiver language both within the same type of waiver and across waivers complicated automation of extraction of mitigations and restrictions. Thus, processing of this data set required a mixture of automated and manual methods.

Automated processing of these data would be enabled by changing the format of these files. Recommended changes involve both mitigations and restrictions. Specifically, identification of the mitigations that enable the waiver would be helpful. An example structure for operations over people is:

Mitigations:

1. M1: Use of parachute system X.
2. M2: Use of aircraft Y.
    a. M2E1: Weight of aircraft is below Y lbs.

Such a structure identifies the mitigations that enable the waiver and also provides reasoning, as needed, which is identified here as an enabler (M2E1). Restrictions (or whatever term is preferred) should also be explicitly listed, such as:

Environmental Restrictions:

1. ER1: Operations may only occur when temperatures …

Operational Restrictions:

1. OR1: At least X VOs must be used.

These recommendations could be strengthened even further by developing identifiers for restriction types, which align with Part 107 waiver categories. With this, restrictions could be provided in the form of identifiers, relations (e.g., less than, greater than, etc.), and numeric values. Regardless of whether this recommendation is followed, use of consistent (and defined) units would enable automated analyses. The A21 team encountered use of multiple units for the same quantity (wind speed restriction, weight restriction, etc.), which further complicated analysis.

Table 5. Summary of data acquired by the A21 team

Data Set:	Data Category:	Beg Date:	End Date:	Data Location:	Source:	Data Format:	Comments:
UAS Detection Data	Tracking/ Trajectory	8/22/2018	4/30/2020	DFW	Collected by ERAU from several sources.		
Part 107 Waivers (Approved) PDFs	Intent	6/15/2016	4/18/2020	UND/ERAU	FAA Website	.PDF files	ERAU and UND have extracted data from PDFs.
Part 107 Waivers IPP Numbers	Intent	6/15/2016	11/4/2019	Shared Drive	FAA	.xlsx file	IPP waivers identified in .xlsx file.
UAS Accident/Incident Preliminary Reports	Safety	4/8/2010	8/21/2014	Shared Drive	FAA Website	.csv file	
UAS Sightings Reports	Safety	11/13/2014	3/31/2020	Shared Drive	FAA Website	.csv files	ERAU extracted reporting sightings and georeferenced with lat/long and FIPS code (5-digit) for geospatial visualization / analysis; .csv files.
LAANC	Intent	7/23/2019	3/31/2020	Shared Drive	FAA	.xlsx file	
MLS Operations	Intent	4/9/2015	2/13/2020	Shared Drive	FAA	.xlsx file	
MLS Accidents/Incidents	Intent	4/9/2015	2/13/2020	Shared Drive	FAA	.xlsx file	
sUAS Registrations--Hobbyists	Registration	12/21/2015	11/30/2019	Shared Drive	FAA	.xlsx file	
sUAS Registrations--Commercial	Registration	3/29/2016	11/30/2019	Shared Drive	FAA	.xlsx file	

Legacy Aircraft Registration Master File	Registration	11/24/1971	12/27/2019	Shared Drive	FAA Website	Comma-delimited, fixed-width text files.	Manned + Unmanned Aircraft
sUAS Registration Service	Registration		2/3/2017	Shared Drive	FAA	.xlsx files	
Visibility Analysis	Safety				Detection Data		
ANSI Standard Roadmap	Safety	12/1/2018	12/1/2018	Shared Drive	FAA Sponsor	.PDF file	ANSI roadmap of future certification efforts (relevant source for milestone events and for Task 2, 3 analysis).
NPRM Documents	Safety	2/1/2019	12/31/2019	Shared Drive	FAA Website	.PDF files	NPRMs, draft advisory circulars for SMS analysis.
Section 352 Sample Responses	Safety	4/12/2019	4/12/2019	Shared Drive	FAA Website	.PDF files	Sample successful waiver applications.
Trend Analysis BVLOS	Safety	??	??	Shared Drive	FAA Website	.PDF file	FAA trend analysis RE: BVLOS waivers.
Trend Analysis OOP	Safety	??	??	Shared Drive	FAA Website	.PDF file	FAA trend analysis RE: Operations over People waivers.
FAA UAS Facility Maps	Tracking/ Trajectory		6/29/2020	Shared Drive	FAA Website	Variety of formats: csv, kml, shp, etc.	UAS facility map data including a .csv, .kml, and GIS shapefiles.
Waiver Safety Explanation Guide	Safety	12/18/2020	12/18/2020	Shared Drive	FAA Website	.PDF	Guidance on waiver process; provides a risk assessment checklist.

4.4.3 MLS Data

The MLS is a data collection system used to collect data from the FAA Test Sites. Data collected with this system includes CONOPS data, flight operations data, and accidents/incidents data. The A21 team has been provided flight operations and accidents/incidents data. These data are being used in various ways to understand trends associated with UAS. Because of this, characteristics associated with the entire data set have been analyzed. It is noted that the A21 team is analyzed these data to understand how data characteristics are evolving over time by breaking the data out by month.

Table 6 provides characteristics for MLS flight operations data. As indicated in this table, data availability ranges from 100% to 0%. This is not surprising given that many MLS data fields are optional. In addition, simple checks for the presence of non-physical/errant values were applied. Such values were identified in five data fields (Flight Hour Calc, Aircraft Type, Operating Altitude, Operating Altitude AGL, and Flight Name). In addition, comments are added to provide more insight as to why data were flagged as being non-physical/errant and to highlight inconsistences (e.g., different naming conventions for the same UA).

Table 7 provides characteristics for MLS accidents/incidents data. As with flight operations data, data availability ranges from 100% to 0%. Nonphysical/errant values were identified with two fields (Fk_COA Flight: Aircraft and Airspace Class at Time of Event). Both of these are associated with inconsistencies in data entries, as indicated in the Table 7 comments.

Table 6. Data characteristics for MLS flight operations data.

Variable	Percentage of Entry	Percentage of No Entry	Non-Physical Values/Errors?	Count of Non-Physical Values/Errors	Description	Comments
Flight Type	99.56	0.44	No			
Flight Hour Calc	100	0	Yes	353 (entries of 0)	Minimum value is 0.	This variable cannot be zero because that would mean the UAS did not fly.
GCS Start	67.79	32.21	No			
GCS End	67.77	32.23	No			
Weather	49.55	50.45	No			
Start Time	100	0	No			
End Time	100	0	No			
Aircraft Type	99.61	0.39	Yes	TBD for the specific aircraft names. 46 (entries for "Aircraft")	Naming and abbreviation differences for the same aircraft. UAS called "Aircraft"?	These differences cause different counts for the same aircraft. Examples: Aerosonde vs. AEROSONDE 3D Robotics Iris + vs. 3D Robotics Iris+
Aircraft Weight	100	0	No			
Operating Altitude	86.94	13.06	Yes	1 (entry with a negative value)	Negative height value.	Must be a positive value.
US State	86.67	13.33	No			
Airspace Class	100	0	No			
Meteorological Conditions	81.78	18.22	No			
Flight Rules	81.77	18.23	No			
Engine Down Time	66.93	33.07	No			
Engine Up Time	66.94	33.06	No			
Launch Latitude	99.92	0.08	No			
Launch Longitude	99.93	0.07	No			

Operating Altitude AGL	99.83	0.17	Yes	1 (entry with a negative value)	Negative height value.	Must be a positive value.
Landing Longitude	99.78	0.22	No			
ID	100	0	No			
Flight ID	14.63	85.37	No			
Flight Name	100	0	Yes	TBD	Multiple flights contain the same flight name. For example: 1/1, 1, Flt 1 etc.	Flights that contain the flight name make it confusing when addressing specific information about a flight.
FK_COA	100	0	No			
FK_COA: Mission	100	0	No			
Flight Time Minutes	100	0	No			
Flight Time Hours	100	0	No			
Aircraft Notes	45.10	54.90	No			
GCS	52.37	47.63	No			
NNumber	87.95	12.05	No			
Modified	100	0	No			
US State County	86.41	13.59	No			
Altitude Determined By	98.02	1.98	No			
Distance	100	0	No			
GCS Latitude	70.01	29.99	No			
GCS Longitude	69.99	30.01	No			
FK_Research Area	89.53	10.47	No			
FK_Detailed Research	25.10	74.90	No			
Status	100	0	No			
Section 333 Exception	1.50	98.50	No			
C2LoSBLos	79.87	20.13	No			
FK_GCS	0	100	No			
GCS Travel	97.85	2.15	No			
Night Operations	92.96	7.04	No			

Operating Altitude Units	98.12	1.88	No
Range	95.28	4.72	No
SACEC	100	0	No
VLoSBVLoS	80.41	19.59	No
Comments	9.88	90.12	No
Imported	56.57	43.43	No
Item Type	100	0	No
Path	100	0	No

Table 7. Data characteristics for MLS accidents/incidents data.

Variable	Percentage of Entry	Percentage of No Entry	Non-Physical Values/Errors?	Count of Non-Physical Values/Errors	Description	Comments
Content Type	100	0	No			
Event ID	89.09	10.91	No			
FK_COA Flight	89.09	10.91	No			
Operator	52.73	47.27	No			
Fk_COA Flight: Aircraft	89.09	10.91	Yes	1 (Birdseyeview FireFly 6) 4 (Birdseyeview FireFly6)	Naming and abbreviation differences for the same aircraft.	These differences cause different counts for the same aircraft. Example: Birdseyeview FireFly 6 vs. Birdseyeview FireFly6
Event Type	98.18	1.82	No			
Event Magnitude	0	100	No			
Start Time	100	0	No			
End Time	23.64	76.36	No			
Aircraft Latitude	23.64	76.36	No			
Aircraft Longitude	23.64	76.36	No			
GCS Location	69.09	30.91	No			
Flight Phase	83.64	16.36	No			
ATC LoS or BLoS	87.27	12.73	No			
Created	100	0	No			
Set Permissions	0	100	No			
Set Permissions VA	1.82	98.18	No			
Item Type	100	0	No			
Path	100	0	No			
Airspace Class at Time of Event	96.36	3.64	Yes	28 (Class G) 4 (G)	Naming differences for the same airspace class.	These differences cause different counts for the same airspace class. Example: Class G vs. G

4.5 Conclusion

The A21 team developed a data catalog, in the form of a Microsoft™ Excel™ workbook, to describe data sets. The catalog is organized into the following sections:

- Data that have been acquired by the A21 team
- Registration: Data providing information regarding Unmanned Aircraft (UA), pilots, and locations
- Intent: Data elements describing intended uses of UA
- Platforms and Models: Provides information regarding UA
- Company-Level Data: Information regarding manufacturers of UAS and UAS components
- Tracking and Trajectory: Information regarding flight tracks and trajectories
- Safety: Data related to safety of UAS operations

Numerous UAS data sets have been acquired. These data have been acquired through multiple means, including:

- Acquisition of publicly available data from data repositories
- FAA provision of data (without a formal request from A21 team)
- FAA provision of data in response to A21 team requests
- Agreements developed by individual A21 team members

Owing to data restrictions (propriety data, etc.), some data requests were rejected by the FAA. These restrictions pose a significant challenge, as lack of data can undermine the team's ability to develop an accurate picture of current and predicted expanded and integrated UAS operations. Development of a data sharing construct that enables access to data while preventing inappropriate data exposure beyond the A21 team would enhance the value of A21 research.

Data characteristics were evaluated for:

- UAS sightings data
- Approved Part 107 waivers
- Mission Loggins System (MLS) data

UAS sightings data were determined to be very complete. MLS data, however, have data element availability that ranges from 0% to 100%, which is consistent with many MLS data fields being optional. In addition, non-physical entries were identified in five MLS flight operations data fields and in two MLS accidents/incidents fields, with the latter being associated with inconsistencies in data entry (e.g., Class G vs. G). Analysis of Part 107 waivers provided significant insights into mitigations and restrictions for approved operations. Analysis of these waivers was completed through a combination of algorithms (computer code) and manual analysis. The Part 107 waiver formatting enabled a partially automated analysis of the waivers. The team manually processed complex, compound, and free-form data elements where automated processing failed.

5 Addendum 2: Technical Report – Data Needs for CONOPS Evaluation

5.1 Introduction

Task 1-2 of A21 seeks to determine the data needs to drive risk-based analysis of UAS systems toward specific CONOPS. The research questions/goals being addressed are:

- What are current UAS CONOPS relevant to sUAS expanded operations including operations over people and other waiverable UAS integration activities?
- What performance metrics must be considered toward determining the performance of a UAS CONOP?
- What data are necessary to evaluate actual or predicted performance under the CONOPS?

These are addressed through the following sub-tasks:

1. Review relevant CONOPS based on existing CONOPS available for relevant organizations and based on inferences from waiver requests
2. Identify data needed to evaluate actual or predicted performance under those CONOPS
3. Solicit additional CONOPS from ASSURE partners, IPP participants, and UAS test sites
4. Complete survey of current UAS CONOPS as identified within the project scope for expanded operations of sUAS
5. Complete survey of current safety assessment metrics and methodologies for UAS waiver approval for identified CONOPS
6. Identify data collection requirements for CONOP safety assessment
7. Identify existing data sets supporting CONOP evaluation
8. Identify data gaps that must be necessarily addressed for CONOP evaluation

5.2 CONOPS Review

This section provides results from previous ASSURE efforts. This section involves subtasks 1 and 4 from the subtask list provided in Section 5.1 of this document.

5.2.1 Results from ASSURE A2 and A18

Task 1 of ASSURE project A11L.UAS.22 Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations (referred to as A18) is the "Development of an Operational Framework for sUAS BVLOS Operations—New Use Cases, Industry Focus, and Framework Expansion". This is a follow-on effort to a task that was completed in ASSURE project A11L.UAS.22 Small UAS Detect and Avoid Requirements Necessary for Limited Beyond Visual Line of Sight (BVLOS) Operations (referred to as A2). Cathey and Hottman (2017) analyzed sUAS BVLOS use cases for A2, and Cathey et al. (2019) updated that analysis. The following provides the results of these studies.

5.2.1.1 A18 Task 1 Subtasks

Task 1 within A18 is has three distinct subtasks:

- Subtask 1a: sUAS Use Case Data Collection/Analysis
- Subtask 1b: Exploration of Framework Expansion
- Subtask 1c: Revision of sUAS RLOS Boundary Recommendation with Collected Use Case Data and for Expanded Operational Frameworks

The focus herein is on Subtask 1a: sUAS Use Case Data Collection/Analysis. Insights from other subtasks will be leveraged where appropriate.

5.2.1.2 A18 Subtask 1a: sUAS Use Case Data Collection/Analysis

5.2.1.2.1 Data Collection

As described by Cathey and Hottman (2017), capture of this information, during A2, was envisioned to occur most effectively through a Request for Information (RFI) in the Federal Business Opportunity (FedBizOps) web site maintained by the Federal Government. This call and response cycle produced some useful information, but it was clear that additional information was needed from users or potential users.

To supplement the information from FedBizOps, data calls were issued to the Technical Analysis and Applications Center (TAAC) (operated by New Mexico State University) List Serve as well as published on an AUVSI (Association for Unmanned Vehicle Systems International) website. The goal was to ensure that the distribution was as wide as possible and to reach the entire community. It is believed that the RFI was distributed as widely as possible.

To supplement the data further, the 333 Exemption Holders information on the FAA website were all reviewed to elicit summary sUAS information. In addition, a unique request was sent to more than 4,400 333 exemption holders for information regarding their operations as well as potential DAA (Detect and Avoid) approaches. Information received as a result of that data call varied in its level of detail but has provided relevant experiential information to generalize use cases. The descriptive categories provided for each response include the following:

- Location
- Platform
- Takeoff Time
- Flight Duration
- Key Altitudes
- Airspeeds
- Climb / Descent Rates
- Flight Patterns

Gathering data regarding BVLOS use cases was challenging. This is driven primary by the lack of maturity of BVLOS operations and, consequently, such operations generally not being allowed by the FAA.

5.2.1.2.2 CONOPS/Use Case Taxonomy

Cathey and Hottman (2017) developed a use case taxonomy for sUAS BVLOS operations that was also utilized by Cathey et al. (2019). Detailed definitions of these use cases are provided in Appendix A.

Aerial Data Collection: Use cases that are either described simply as "Aerial Data Collection" (or have a very similar description) or can most accurately be described as a use involving the collection of data by means of sensors or cameras onboard the sUAS. Separate from the definitions of "Aerial Surveying/Mapping," "Agriculture," "Inspection," and "Research,", the description given of the use case is not necessarily specific as to what data are collected and for what purposes data are collected.

- Aerial Data Collection – Construction/Mining
- Aerial Data Collection – Environmental
- Aerial Data Collection – General
- Aerial Data Collection – Insurance

Aerial Photography/Videography: Use cases that are either described simply as "Aerial Photography/Videography" (or have a very similar description) or can most accurately be described as a use involving the collection of pictures and videos for no other obvious or implied reason than to have the pictures or videos collected in the applications listed below.

- Aerial Photography/Videography – Closed-set filming
- Aerial Photography/Videography – Construction
- Aerial Photography/Videography – General
- Aerial Photography/Videography – News Gathering
- Aerial Photography/Videography – Outdoor Activities
- Aerial Photography/Videography – Real Estate
- Aerial Photography/Videography – Wedding

Aerial Surveying/Mapping: Use cases that are either described simply as "Aerial Surveying/Mapping" (or have a very similar description) or can most accurately be described as a mapping or surveying operation for various purposes.

- Aerial Surveying/Mapping – Agriculture/Mining
- Aerial Surveying/Mapping – Construction
- Aerial Surveying/Mapping – Engineering
- Aerial Surveying/Mapping – General

Agriculture: Use cases that are either described simply as "Agriculture" (or have a very similar description) or can most accurately be described as a use involving the collection of data for agricultural purposes.

- Agriculture – Crop Monitoring
- Agriculture – General
- Agriculture – Precision Agriculture

Emergency Services: Use cases that are either described simply as "Emergency Services" (or have a very similar description) or describe a use case that can be described as aiding police officers, firefighters, medical services, etc., or in the investigation of areas that are too dangerous to put a human being in for investigative purposes.

- Emergency Services – Crisis Response
- Emergency Services – General
- Emergency Services – Investigation of Hazardous

Flight Training/Education: Use cases that are either described simply as "Flight Training" or "Education" (or have a very similar description) or describe a use case involving the training of employees, students, or other users in the operation of sUAS technology and/or procedures. Use cases involved in educating individuals on sUAS principles or in demonstrating concepts in mathematics and sciences that can demonstrated by sUAS technology.

- Flight Training/Education – Education
- Flight Training/Education – General
- Flight Training/Education – sUAS Training

Inspection: Use cases that are either described simply as "Inspection" (or have a very similar description) or that describe a use case involving the inspection of different kinds of structures or areas for safety, upkeep, maintenance, etc.

- Inspection – Communications Structures
- Inspection – Construction
- Inspection – General
- Inspection – Insurance
- Inspection – Oil/Pipeline
- Inspection – Power Plants
- Inspection – Real Estate
- Inspection – Structure
- Inspection – Wind Power

Marketing: Use cases that are either described simply as "Marketing" (or have a very similar description) or describe the capture of aerial images and videos for the express purpose of using these images and videos for the marketing of a business, product, or service.

- Marketing – Aerial Images
- Marketing – General

Multiple Applications: Use cases that are either described simply as "Multiple Applications" (or have a very similar description) or have been cleared for more than one general use case.

Research: Use cases that are either described simply as "Research" (or have a very similar description), or describe a use involving imaging and data collection distinctly for scientific research purposes.

- Research – Academics
- Research – Development
- Research – General
- Research – Market
- Research – Operations
- Research – Product Testing
- Research – Transportation

Search/Rescue: Use cases that are either described simply as "Search/Rescue" or describe a scenario where a sUAS platform would be used to aid in various search-and-rescue operations.

Surveillance, Monitoring, etc.: Use cases that are either described simply as "Surveillance" or "Monitoring" or have a description that can be categorized in a similar fashion.

- Monitoring – Environmental
- Monitoring – General
- Monitoring – Legal
- Monitoring – Safety
- Monitoring – Security

One additional category is added as a catch-all entitled "Other UAS Applications". This was established to capture either novel or unique use cases that do not fit well into the taxonomy above and do not have the significance to be a stand-alone category, or variations on applications to the use cases already defined.

5.2.1.2.3 <u>CONOPS/Use Case Applications</u>

The research conducted in A18 to assess use cases attempted to categorize the various applications and map them into the structure noted above. Some of these use cases have grown in the number of uses (since A2 was completed). Some of these applications are still noted but did not appear or had limited references in the literature or online. A good example of an application that is widely used but not noted as a stand-alone reference is Aerial Photography/Videography for Real Estate. Thousands of images are available online, but the process for providing these is not noted. In some ways this demonstrates the mainstream nature of the technology.

Some applications are not necessarily new (relative to A2) but are instead adaptations or combinations of technologies or uses. For example, the applications of "Aerial Data Collection – Environmental", and "Surveillance, Monitoring, Etc. – Environmental" fit in the specific case for anti-poaching and wildlife protection as a general area, but the number and varied approaches to do this are very different. They all fit within the broader category and the specifics vary widely under this same umbrella. The A18 research team noted over and over again that there were expanded applications under a previously defined top-level category. The mashups and diversity have redefined the ecosystem, yet they still generally fit within the original taxonomy.

The sections below do not attempt to document every published application, as doing so is impossible. There are many examples of the same application by different groups. The sections below attempt to present representative applications within each area. These are presented to show interest and to demonstrate the use cases and, in some cases, the dynamic nature of these various areas. The use cases found and detailed below once again demonstrate the statement that UAS applications are only limited by one's imagination.

5.2.1.2.3.1 Aerial Data Collection

Aerial Data Collection –Construction/Mining. The application for UAS in construction and mining has significantly expanded. Many of the references note the cost savings in general, but do not provide specifics of the magnitude of the savings. Terra Drone (Karpowicz 2019) notes drone-based solutions for oil and gas, mining, solar, wind, and infrastructure inspection all over the world. The claim is that using their novel autonomous flight system and 3D modeling system software make it possible to generate high-precision maps/models. Some UTM (Unmanned Traffic Management) applications are noted. The regulatory challenges vary within the 25 countries where they operate.

Another interesting application is Flyability's (Flyability 2019a) use of photogrammetry to build 3-D models of indoor spaces. The drone-based photogrammetry is focused on indoor and inaccessible places. This can be extended to mine inspection. The article defines the modeling, measurements, data volume, and processing. It allows for checking conditions of structures, tracking changes, and planning maintenance and design changes. Training for safety is highlighted. Some of the environments and challenges are also noted. A specific use case (Flyability 2019b) details how a previously impossible-to-inspect gold mine is mapped in 3D using photogrammetry from a drone.

Aerial Data Collection – Environmental. Aerial data collection for environmental applications is quite broad. Strochlic (2017) captures a large number of ways drones are used to save lives. The push in this area is not so much financially driven but is to aid others. "Among the most eager to harness the power of remote-controlled aircraft are aid and service organizations—those performing dangerous humanitarian and conservation tasks in the world's hard-to-reach areas. Drones are monitoring vultures on the steppes of Mongolia, delivering medical supplies in Rwanda, and searching for lost civilizations in Brazil."

sUAS are also being used for environmental monitoring of shorelines in the Chicago Park District (Lillian 2019a). The desire is to evaluate erosion caused by high lake levels through capturing footage of the Chicago shoreline. The flight efforts were contracted out and the "Chicago Park District is working with the City of Chicago, the U.S. Army Corps of Engineers and city aldermen to develop a shoreline study for the entire 18-mile stretch of Chicago's lakefront." It was noted that the study is designed to help identify near- and long-term sustainable strategies to address erosion and storm damage.

Black Swift Technologies (2019) was chosen for an arctic research project in Greenland. The Institute of Arctic and Alpine Research, part of the University of Colorado Boulder, will use an advanced aerial research platform to conduct high-altitude, high-latitude atmospheric research studies in Greenland. The goal is to measure the amount of water vapor above the ice sheet and its isotopes. This can provide insights into the water vapor's origins and whether it is coming from the ice sheet or the atmosphere.

Aerial Data Collection – General. Aerial data collection can be used to help reduce the risk of injury. Pitcher's (2019) article "Drones Do Deadly Work So You Don't Have To" makes the case for using sUAS for applications to keep humans out of potentially dangerous or injury-prone situations. "Flying machines don't fall off ladders and can safely go places that put workers' lives at risk." He notes that "more than a thousand U.S. laborers have been killed working in confined spaces like that in the past decade." Applications for cell tower inspection, confined spaces, and painting structures are noted as potential ways to reduce worker risk.

Aerial Data Collection – Insurance. The positive disruptive nature of drone use throughout the insurance industry is highlighted by Zimlon (2019). "Insurance companies already employ 17% of all commercial drones. Drones can play a part in all the stages of the insurance lifecycle, especially claims management and fraud prevention." Other areas noted with positive impacts by drones include risk assessment, accelerating claim management, fraud reduction, employee safety, and the non-technical advantage of improving customer experience during catastrophes.

5.2.1.2.3.2 Aerial Photography/Videography

Aerial Photography/Videography – Closed-set Filming. A number of companies specialize in this area. It is a common application that independent companies have monetized. No additional notes are provided on closed-set filming.

Aerial Photography/Videography – Construction. Construction was one of the early areas to use sUAS for support. Drones can be used for a myriad of efforts. Anderson (2015) provides a top-level overview in "7 Great Uses for Construction Drones". He details the planning process, surveys, data analysis, client progress tracking, job site monitoring, structure inspection, focus on better safety records, and keeping projects on track and on budget.

Aerial Photography/Videography – General. Many different areas fit within this catchall category. One worth including is the facilitation of using drones now that LAANC (Low Altitude Authorization and Notification Capability) has been rolled out. Murphy (2019a) describes the impact of the FAA expanding LAANC to include recreational drone pilots. "Only commercial pilots with Part 107 certification were allowed to fly in restricted or controlled airspace before Tuesday's ruling. This latest development gives recreational flyers, who were previously restrained by contradictory rulemaking, access to the 600 airports that currently participate in the LAANC program."

Aerial Photography/Videography – News Gathering. There is an expanding market to provide support for news gathering. The article "Measure to Provide Drone Service Solutions Broadcast News Operations" (Schrothon 2017) details an approach to providing this support. "Measure, a provider of drone services to enterprise customers, has introduced a training, equipment and support toolkit designed for broadcast news organizations that seek to use their own crews for drone-based news gathering. The toolkit is an option to Measure's turnkey broadcast news service, giving media and broadcast companies the option to outsource all drone operations to Measure's expert pilots or instead leverage the toolkit to capture their own footage."

It also highlights the hardware, training, maintenance and repair support, insurance, regulatory support, and help desk assistance.

Aerial Photography/Videography – Outdoor Activities. Drones are regularly seen at sporting and entertainment events. These have been used for both entertainment and security. A few examples are presented here. From an entertainment outlook, probably the most well-known demonstrations are from the Intel and Disney partnership (Business Wire 2016). The article, "Intel, Disney Light Up the Sky Over Walt Disney World Resort with New 'Starbright Holidays' Drone Show" shows how "Intel and Disney demonstrated the future of light shows with holiday show-drone performance at Disney Springs at Walt Disney World Resort. Innovative Intel Shooting Star™ drones are super light and designed for customizable commercial entertainment light shows. Collaboration exemplifies how the two companies continue to push the boundaries of what's possible to create an amazing entertainment experience."

These same Intel drones have been used at other very public spectacles. This has included the Olympics and the most recent Super Bowl (Moore 2019). While pilots flew 150 Intel drones inside the "Mercedes-Benz Stadium for a first-ever live Super Bowl halftime performance on Feb. 3, another team was perched on a rooftop flying security over watch with a tethered quadcopter. Both operations reflected the state of the art in the ongoing mission to make unmanned aircraft trusted participants in major events." These tools are providing security and law enforcement new insights and perspectives. The UAS teams "provided thermal and visual images to the public safety command centers, responding to requests to take a closer look at areas of interest and in constant two-way communication during shifts that began at noon and ended at midnight (a little later on game day). U.S. Army Black Hawk helicopters and U.S. Air Force F-16s patrolled the skies to enforce a temporary flight restriction that extended 30 miles from the stadium during the game … also reported to be on patrol was a trio of drone-hunting drones operated by Fortem Technologies."

UAS were part of the security provided at the Copa America soccer tournament this past summer (AUVSI News 2019a). "Autonomous UAS designer and manufacturer Atlas recently partnered with the Military Police of Rio de Janeiro State (PMERJ) to utilize its AtlasPRO UAS as part of the PMERJ's overall security efforts for the Copa America soccer tournament." It was noted that "using this technology, an operator can divide missions among several UAS and maintain constant 'eyes in the sky' using autonomous hot-swap capabilities, which means once a UAS runs out of battery, a second AtlasPRO takes off to replace it above a point of interest."

As one can see from the above examples, these applications are for outdoor activities but also cross over to public safety and security. It is often the case that more than one area is being addressed in a single application.

Aerial Photography/Videography – Real Estate. An article by Altitude (2019) titled "Drones Are Upping the Game in Real Estate Marketing with Aerial Photography" provides a succinct summary of this use case. "UAS use for aerial photography for real estate sales is one of the obvious sUAS applications. Early adopters have used this technology to provide a new angle on home sales. This article provides a discussion of the benefits of drone use for aerial photography, which include views of new perspectives, better marketing for faster sales, creating potential buyer interest (buzz), and making the marketing easier.

Aerial Photography/Videography – Wedding. Capturing the special day is a niche market. Many photographers and stand-alone companies offer UAS services for recording weddingsMany photographers have added this element to recording this day. Many stand-alone companies do this as well. This use case has spread nationally and internationally. No specific references are provided for wedding photography.

5.2.1.2.3.3 Aerial Surveying/Mapping

Aerial data collection covers a broad number of applications. Aerial surveying and mapping are subsets of that type of data. Surveying and mapping applications are more specific and are thus broken out herein. Repetitive information is not included, but the parallels are noted.

One specific article, "UAE Using Drones and AI to Map Desert Landscape" (Smith 2019), describes how "drone technology is now assisting with census and mapping of wildlife and green cover in a unique UAE aerial drone project. The environment ministry of the Emirates is meticulously capturing the country's desert environment to support future growth." The goals are far reaching, and they are using the images and information captured for multiple purposes. "The aerial project to capture wildlife and trees across the Emirates has completed its first phase, giving a fascinating statistical insight into the country's natural habitat. Every fruit tree and ghaf tree, water well and farm is being mapped to support future planning." This operation, led by the environment ministry, covered 550 km^2 of agricultural lands across Dubai, Sharjah, Ajman, and Umm Al Quwain, providing "a wealth of raw information that is being analyzed through leveraging AI technology."

The level of detail is significant. The information is not estimated. They note the "presence of 5,637 farms – 895 growing crops and 2,919 rearing animals. Detailed data shows that the crop farms comprise 35,535 fruit trees and 200,230 trees that serve as windbreakers. The survey also tracked the presence of 5,635 farm buildings – labour accommodation, barns, and warehouses, among others – 362 wells, and 3,447 protected farms – 2,635 of them use netting to protect their crops. Ghaf trees accounted for 73,344 of all trees on these farms." They are also producing accurate estimates of the volume of irrigation water used by agricultural holdings.

Aerial Surveying/Mapping – Agriculture/Mining. As noted above, there are many diverse applications in this area. Karpowicz (2019) details a number of very different applications that Terra Drone is executing in 25 different countries around the world. The mapping functions are central to these. Flyability (2019a, b) defines high-level requirements for surveys and mapping. The gold mine 3D modelling is an excellent use case demonstrating the power of this technology for mining.

Agricultural applications for surveying and mapping are front-end elements required for all of the specific agricultural applications. Crop monitoring, precision agriculture, etc., are based on having accurate maps and survey information. Details of the applications related to agriculture are provided in Section 5.2.1.2.3.4 below.

Aerial Surveying/Mapping – Construction. Many civil engineering and construction companies are using drones for surveying and mapping as part of their projects. The maturity has of this use case has grown to the point where it is no longer new and novel. Countless web sites describe this capability as part of engineering firms' set of tools for their work. These are not defined in any further detail here.

West Texas and Eastern New Mexico are two of the areas central to the latest expansion in oil and gas production related to advancements in shale technology. In the article "Region's growing alternative energy opens new market for drone company", McEwen (2019) details drone use in the Permian Basin supporting the oil and gas industry. Many of these applications are in advance of or part of ongoing construction activities. Applications also include looking for methane and pipeline leaks and scouring pipeline routes and well locations. Drones are also being used on wind farms, solar panels, transmission lines, and for pre-mapping in advance of operations.

Aerial Surveying/Mapping – Engineering. A repeated example of drone flights for a specific engineering application is the shoreline studies in Chicago (Lillian 2019a) noted above. Flights were completed by a professional contractor and survey maps generated. Again, as noted above, the study is designed to help identify near- and long-term sustainable strategies to address erosion and storm damage.

Inspections of solar farms (Murisonon 2019a) have been completed. senseFly developed a fixed-wing thermal drone solution designed specifically for solar farm inspections. The flight system was developed in collaboration with the software company Raptor Maps and "promises to enable an automated assessment of solar plant performance at a sub-module level". The system uses an "eBee X fixed-wing drone, senseFly's Duet T thermal mapping camera, and Raptor Maps' solar-specific software". senseFly says the package can be "easily integrated into solar management workflows without requiring either drone piloting skills or the manual analysis of aerial solar farm data."

Aerial Surveying/Mapping – General. Refined approaches toward drone-based crime scene investigation have been developed. Two different but complementary applications are detailed by RBR (2019). Two incidents highlight the ability of aerial drones to help public safety with crime scene investigations and public safety incidents. The first application is for a standoff situation in which the drone provided a real-time perimeter scan and more consistent video footage than the county's helicopter. The information helped map out the area and was used to adjust the team's tactics, specifically in the use of tear gas. A second UAS application was how a "demonstration recreated a homicide scene at a local equestrian park", showing how drones can capture forensic evidence at the scene in the dark and map it in 2D and 3D for law enforcement use. Similar content demonstrating the value of drones at crime scenes is provided by Miller (2019a).

Aerial mapping for environmental applications is supportive of desired program outcomes. As noted above, Strochlic (2017) captures a large number of ways drones are saving lives; the mapping of the areas is key to forming the action plans. Coral mapping in the American Samoa is a good example of this.

5.2.1.2.3.4 Agriculture

Agriculture – Crop Monitoring. Geiver (2018) presents an Excellent survey of how drones are being adopted by farmers for crop monitoring. The article notes a growing investment in the technology by farmers focused on precision agriculture or smart farming. "According to a study recently unveiled by Munich Reinsurance America Inc., nearly three-fourths of all U.S. farmers 'are currently using or considering adopting the technology to assess, monitor and manage their farm.'" Of note is that some flights are is done by farmers themselves, and approximately half of the flights are contracted out.

Agriculture – General. Various applications can fit within this area that address the elements of crop monitoring and precision agriculture. Applications include insect monitoring, soil moisture measurements (evapotranspiration), water runoff, etc.

Agriculture – Precision Agriculture. There are almost too many articles to point to regarding drones and their use in precision agriculture. The obvious applications for mapping, plant health, soil moisture, etc., are becoming routine. In some cases, the novelty of these flights has worn off since they are becoming routine, and fewer big-picture references are being published. Most of the applications noted are for specific unique applications.

McNabbon's (2019a) article "Taking Drones in Agriculture to the Next Level: the SmartFruit Project" is focused in one way on food security. "The 'SmartFruit' project is a large undertaking: one that will examine areas of precision agriculture including remote sensing, phenotyping, proximal sensing development, and robotics." The "team will establish a network of drone charging stations through wireless internet connections and integrate the network with an existing satellite remote sensing system. That will allow all of the survey, data collection, and analysis to be remotely operated and managed from the central laboratory – located more than a hundred miles from the field."

One of the more interesting and unique applications of drones in precision agriculture is detailed by Antunes (2019). In the article titled "How can a Flamethrower on a Drone be Utilized by Commercial UAS Operators?", the author details several applications where this makes logical sense. "Farmers have been using the 'flame weeding' method to destroy the plant structure in the weed leaves so they can no longer perform photosynthesis and grow." The application is to put the flamethrower on the drone to better perform this task. These burns obviously require precision in the application process. The system is designed to incinerate "weeds and other unwanted ground plants" as well as "ground-clearing or controlled agricultural burns". Applications to clear power lines are also noted.

5.2.1.2.3.5 Emergency Services

Emergency Services – Crisis Response. Crisis response is an expanding area for UAS use. As noted above, RBR (2019) highlights how drones enhance help public safety during public safety incidents. UAS use during a standoff situation highlights how a drone can provide a real-time perimeter scan and more consistent video footage. The information helped map out the area and was used to adjust the team's tactics, specifically the use of tear gas.

Another challenging potential crisis is when a radiation leak happens. This can be both for operations at a nuclear facility or when there is a bad-actor event. Knight (2018) notes how drones can be used for radiation detection. "Equipped with the right sensors, unmanned aerial vehicles (UAVs) can help determine radiation levels after incidents in nuclear facilities as well as during routine monitoring." The article compares UAS use with traditional measurement/monitoring methods. Also highlighted are UAS and vibration imaging for inspection of welds and other vibration sensitive assets. The author provides an assessment of the challenges and opportunities associated with coupling with ground vehicles.

Emergency Services – General. A very analytical examination of UAS use in the public sector with a focus on safety and emergency services is provided by Gettinger (2018) of Bard College. The "Public Safety Drone: An Update" report is very detailed-oriented. It notes that at least 910 state and local police, sheriff, fire and EMS, and public safety agencies have acquired drones in recent years. Law enforcement agencies make up two-thirds (599) of the public safety agencies with drones. The majority of drones operated by public safety agencies are consumer and prosumer models. There are more than twice as many public safety agencies with drones as there are agencies with manned aircraft. The report includes details on agency type, location, and drone type.

In a tangential way, the use of a flamethrower on a drone detailed above (Antunes 2019) has the potential to support some emergency applications, specifically related to clearing power lines and a few other operations. "The Surprising Ways Drones Are Saving Lives" (Strochlic 2017), also detailed above, points out a number of applications, including tracking people fleeing from disasters.

Emergency Services – Investigate Hazardous Regions. The Bard College (Gettinger 2018) and Knight (2018) reports on radiation detection have aspects that are applicable to investigations in hazardous regions. The most recent UAS application that made headlines was noted by Zazulia (2019) in an article titled "Notre-Dame Cathedral Fire Fought with Drones". "French firefighters used two DJI drones equipped with cameras to help gauge the scene and effectively position firehoses to combat the blaze, as first reported by French newspaper Le Parisien. It is thanks to these drones, to this new technique absolutely essential today, that we were able to make tactical choices to stop this fire at a time when it was potentially occupying the two belfries. The drones made it possible to properly engage the means at our disposal." There is no doubt that proper application of these technologies can help in hazardous situations.

5.2.1.2.3.6 Flight Training/Education

Flight Training/Education – Education. An increasing number of teachers are using UAS for educational purposes. UAS are being used to teach first principals and as research platforms. The application areas extend across the various taxonomy categories included in this document. A review of the related articles shows that this is an expanding area. Without going into all education-related use cases, two are highlighted below.

Lillian (2019b) details the partnership between Kansas State Polytechnic and Simlat that focuses on BVLOS UAS training. This work was part of the FAA's Integration Pilot Program (IPP) and BVLOS simulator training was offered. This was a seven-day immersive course with a plan to expand to UAS degree-program offerings. Sinclair College (2019) is offering an Unmanned Aerial Systems UAS.S.AAS, Associate of Applied Science through the Sinclair Department of Aviation Technology. The online description defines program structure (curriculum), outcomes, and career opportunities. It should be noted that these two ASSURE schools are part of the FAA UAS Center of Excellence.

Flight Training/Education – General. For the Kansas State Polytechnic program, as noted by Lillian (2019b), is expected to expand to UAS degree program offerings. Other schools like Embry-Riddle are also moving into this education space.

Flight Training/Education – sUAS Training. A number of small sUAS training programs exist. These are easily identified using a web search. The National Training Aircraft Symposium (NTAS) provides insight regarding aviation in general, with UAS included. "NTAS serves as a forum for aviation professionals from academia, government, and industry to exchange ideas and learn about ways to address problems in the aviation industry." NTAS focuses on UAS training, implications for pilots, and integrated airspace for manned and unmanned vehicles.

5.2.1.2.3.7 Inspection

Inspections using UAS cluster around a core of a few goals, including reduced cost, improved safety, time savings, improved data collection, improved accuracy, and more. The sections below highlight some of these different aspects.

Inspection – Communication Structures. Inspection of communication towers is a logical case for sUAS operations. "AT&T Signals It Will Use Drones for Tower Inspections" (DJI 2019) highlights how initial drone trials were completed. The plan is to use this approach for tower operations and for UAS to serve as "surrogate tower climbers". Inspections will be for engineering and technical reasons as well as for bird-nest evaluations.

Inspection – Construction. The Karpowicz (2019) article "Terra Drone Seeks to Become the Top Industrial Drone Solutions Provider in the World, Commercial UAV Expo Europe" details a number of construction-related inspections. Details are presented above and not repeated here.

Inspection – General. Many applications fit under "General". The two Flyability (2019a, b) articles touch on this and are not repeated here since they are covered above. Two examples of inspection that fit in this category are transmission/power line inspections and inspection of bridges. AUVSI News (2019b) describes how the Maui Electric Company is using UAS to conduct routine aerial power line inspections. The idea is to use both UAS and helicopters to conduct routine aerial power line inspections and demonstrate how cost-effective UAS use is in remote areas.

Detailing similar line inspections, Schmidt (2019) drills down on how photogrammetry will replace LiDAR in transmission line inspections. "A Polish UAV manufacturer recently launched the innovative photogrammetry-based algorithm for transmission line modelling. It is to replace costly helicopter inspections. FlyTech UAV recently launched Innovative long-range electric power lines modeling with fixed-wing aerial data. The solution cuts down on the time spent in the field and promises significant cost reduction. The innovative photogrammetry-based algorithm allows for power line reconstruction and preparing the LiDAR-quality data with aerial imagery only, which dramatically reduces total labor costs, in comparison to methods employing helicopter and LiDAR. Using an efficient flying wing BIRDIE allows to cover up to 10 km of transmission lines in one, 60-minute BVLOS flight." The article notes that the telemetry range is no longer a limitation because the BIRDIE is equipped with unlimited GSM (Global System for Mobile communications) connectivity. A specific use case for cost reduction is provided.

Dormehl (2018) details how UASs are used to keep tabs on existing infrastructure such as bridges: "Intel wants its fleet of drones to monitor America's aging, unsafe bridges". The specific reference explains that a deal was struck to "the Minnesota Department of Transportation and Kentucky Transportation Cabinet to prove it. The collaboration will see Intel's cutting-edge drone technology used to carry out inspections of bridges in the regions." The approach uses high-resolution images converted into 3D data for actionable information.

Inspection – Insurance. UAS use for insurance applications generally falls into the two categories, before and after. The "before" category includes inspections and assessment-type flights. The "after" flights are generally post-disaster assessment-type flights. The American Society of Home Inspectors (2019) article titled "Drones for Inspecting Roofs for Home Insurance Are Becoming the Norm" is a balanced assessment of the potential. "Drones offer fantastic, labor-efficient technology for close up view of roofs and can be operated from the ground. They are well-equipped with modern software which makes inspection and report generation easier." The four main areas covered in this article are 1) roles of drones in home inspections, 2) references to FAA guidelines, 3) recommendations of some of the best drones to use, and 4) the pros and cons of using drones for home inspection.

Stories of post-disaster response use of drones by the insurance industry are common. Some insurance companies prominently show drones in their television commercials as part of demonstrating how they respond to disasters. The article "Insurance Industry Use of Drone, Aerial Imagery Soared After 2018 Southeast Disasters" by O'Connor (2019) provides a representative overview of these "after" applications. "Insurers were able to see the impact immediately and get straight to work handling claims for their customers and gather data from the events from aerial images. Industry has noted an increased use of drones for post-catastrophe inspections compared with last year because of Hurricanes Florence and Michael in the Southeast and the wildfires in the West." The field appears to be growing. "PrecisionHawk had about 40 drone pilots actively working on claims inspections in the wake of Hurricane Florence and worked with about 20 or so carriers in the area of the storm." Looking ahead, the future approach is to marry the high-resolution aerial imagery with machine learning. With all new technologies, there is the question of just where the human and technology interface should reside. Some in the industry have concerns with just using the imagery and need/require human inspections as well.

Inspection – Oil/Pipeline. UAS applications that are focused on oil and gas in the energy sector have been varied. As previously noted, Karpowicz (2019) describes drone-based solutions for oil and gas as well as other applications around the world and notes some of the regulatory challenges within the 25 countries in which they operate. A prime example of a specific oil and gas use case is the pipeline inspection completed by the University of Alaska Fairbanks (UAF) team. This was part of an IPP project and was the first truly BVLOS flight in this arena (McNabbon 2019b). The DroneLife article "Inside the First Truly BVLOS Quadcopter Drone Flight Without Ground Observers – A 4 Mile Linear Inspection Along the Trans-Alaska Pipeline" presents an overview of the UAF IPP testing. It highlights the BVLOS inspection of 4 miles of Trans-Alaska pipeline and defines the systems used to complete the work.

External visual inspection of pipelines is one application. Using drones to collect data with other monitoring devices has been proposed. In Geiver's (2019a) article "Drone developer, fiber optics firm partner to monitor pipelines", the case is made for using UAS to collect "health" data in flight. The plan "… will use drones and fiber optics placed inside a pipeline to monitor for pressure changes, leaks or disruptions along pipeline corridors." A company, E'Kabel, will provide fiber optics that monitor temperatures and vibrations. "As part of its operations, SkyX has developed a unique vertical-take-off-and-landing drone that doesn't require launching strips or on-site piloting. The system includes mobile stations that can be placed along the route of the pipeline to allow the drone to recharge after flights of up to 65 miles or roughly 90 minutes. To ensure the UAV can capture the appropriate data, the drone can fly at speeds as low as 40 mph while reaching maximum speeds of 75 mph."

Another aspect relevant to oil and pipeline UAS operations is demand has grown to the point that third parties are now offering services to support customer needs. In Geiver (2019b) article "Success for several drone service firms continues in the oilfield", the focus is on the announcement of new partnerships that address this inspection space. Elements include the creation of a "robust, efficient multirotor platform equipped with a unique SeekOps designed gas sensor". Also detailed is a "topographic survey and site monitoring company to perform beyond visual line of sight operations in Africa". They monitor hundreds of miles of pipeline. The systems include "live feed capabilities and an array of customizable sensors, including an EO/IR camera, to accumulate high-quality visual data. Proprietary AI systems then analyze the data captured to produce high-impact reports from each scan."

Inspection – Power Plants. Power plants have used UAS for a number of different activities. These include perimeter security; building, structure, and tower inspections; construction applications; and leak detection. As presented above, Knight (2018) notes how drones can be used for radiation detection. "Equipped with the right sensors, unmanned aerial vehicles (UAVs) can help determine radiation levels after incidents in nuclear facilities as well as during routine monitoring."

In the article "Mitsubishi Hitachi Launch Boiler Inspection Drones", Reaganon (2019a) discusses the exploration of applying this new technology. Mitsubishi Hitachi is "bringing drone-inspection technologies to check out boilers and similar large-scale indoor structures." The conglomerate plans to offer the industrial-level service starting this month. Locating weak spots or areas for repair in that kind of infrastructure could avert several types of industrial and utility disasters. They completed tests to confirm the capability for autonomous flight without using GPS (Global Positioning System) or other satellite positioning systems. "Last year, Hitachi was awarded a contract for the development of the 'Fukushima Robot Test Field' drone flight management system. The 'Fukushima Robot Test Field' is the only test center with a drone operations management function at the Japanese large-scale demonstration laboratory. The goal of the test center is to further advance BVLOS drone flights. Unifly and Terra Drone provide the technical UTM backbone to ensure safe BVLOS drone flights at the test center."

Inspection – Real Estate. References to UAS being used, as part of real estate inspections, to examine roofs, walls, foundations, etc. are common.

Inspection – Structure. In the Knight (2018) article noted above, use of UAS and vibration imaging for inspection of welds and other vibration-sensitive assets are highlighted. This can be used on structures. NMSU (New Mexico State University) supported the first inspection of a dam using a drone at the Elephant Butte Dam in New Mexico.

In "Bridge Inspection Drones – Can They Cut Down Costs and Improve Efficiency?", Dronelli (2017) presents how drones can be used for bridge inspections. He details the potential with five different models, the type of camera system they have, range, flight duration, and price. While the industry and products have improved in the past two years, the argument for application remains valid.

Inspection – Wind Power. This particular area is a solid stand-alone market that is growing. At the time of completion of the A18 report, over 1,500 wind turbine technician jobs were open and many of those used drones. Service companies provide support for this industry. The Karpowicz (2019) article "Terra Drone Seeks to Become the Top Industrial Drone Solutions Provider in the World" details a number of inspections related to wind power. Details are presented above and are not repeated here.

Johal and Pfeiffer (2017) note that "drone-based inspections provide cost reduction and revenue enhancement opportunities of over $600/turbine when compared to ground-based inspections. The savings value is two folds ($1200/turbine) when compared to corrective/reactionary maintenance." They describe how one service provider, Measure, performs a blade inspection, including data collection, improved accuracy/information, and asset management.

5.2.1.2.3.8 Marketing

Marketing – Aerial Images. Aerial images, both still and video, are regularly used in advertisements and for marketing purposes. The applications have become so common that they are now a part of the standard tools used in marketing. No additional references are noted because of how common this use has become.

Marketing – General. Marketing is an interesting area because the act of performing a service with a drone can also be a form of marketing. The examples below generally result in this dual-purpose impact. "Uber Eats Moving Forward with Urban Drone Delivery, Powered by New Computing Platform" by McNabbon (2019c) shows this broad impact. "Drone delivery is a technology with far-reaching significance – not just because it has the potential to change the nature of residential delivery, but because it pushes so many boundaries of commercial drone applications: flight beyond visual line of sight (BVLOS), sense and avoid technology, flight stability, and more. Uber Eats successfully tested its first food delivery by drone recently, in a high-density urban area …" The specific act of delivery was direct marketing.

In support of this effort were VOXL and ModalAI. "VOXL is a computing and communication platform that utilizes the smartphone ecosystem to create a highly-integrated, machine vision-based, autonomous navigation system for indoor, outdoor ground robots and drones." "ModalAI is a leader in autonomous robot and drone perception and communication systems. The company develops highly integrated artificial intelligence (AI)-powered modules that empower companies in a variety of industries to utilize aerial and ground autonomous navigations systems that communicate via 4G and 5G cellular networks. ModalAI was founded in June 2018 by former Qualcomm Technologies employees and is built on more than five years of research and development in the drones and robotics market." UAS are set to make food deliveries in Holly Springs, North Carolina (AUVSI News 2019c). This is part of the IPP program.

5.2.1.2.3.9 Multiple Applications

The Multiple Applications category has broadened over time. Some systems are being designed for single-purpose applications, but many are targeting multiple uses. The applications noted above by Terra Drone (Karpowicz 2019) target multiple industries like oil and gas, mining, solar, wind, infrastructure inspection, and more. The article by Pitcher (2019), "Drones Do Deadly Work So You Don't Have To", makes the case for using sUAS for applications to keep humans out of potentially dangerous or injury prone situations. Again, a broad set of applications is noted. In an effort to market to the widest possible set of users, many UAS manufacturers are providing information or demonstrations of their product for multiple applications.

An example of how commercial services market to a broad number of applications and can be used for multiple applications can be found in "Intelligence in Motion" (Measure 2019). Quoting this commercial service, "We provide expert services for your organization's mission critical assets using drone technology. Through state-of-the-art data collection and analysis, and comprehensive program software, we are able to deliver transformative intelligence that optimizes energy production, protects people, and improves infrastructure, all while simplifying maintenance and management processes." They advertise Turnkey Aerial Inspections, Drone Program Toolkits, Advanced Pilot Training, Drone Data Analysis, and Drone Advisory Services.

5.2.1.2.3.10 Research

With the state of the industry, a large number of developers of vehicles, systems, and components require research flights as part of their development. Development of processes and procedures are also part of this research cycle. Research activities are driven by private industry, government, and academia. It is difficult to combine all of these into a simple description of the research being conducted. The research element is at the foundation of many broad efforts. Instead of trying to capture this entire area with many examples, the sections below highlight one or two examples that demonstrate the diversity and vitality of the subsection.

Research – Academics. RouteScene (2019), "Lidar Archaeology – Identifying 700 year old structures", is an excellentexcellent example of UAS research in academics. The goal of these Lidar archeology efforts is mapping of the Canyons of the Ancients National Monument. "Crow Canyon Archaeology Center and the Canyons of the Ancients National Monument looked to map Sand Canyon an ancestral Pueblo site. They knew traditional mapping would not suffice. Using UAV (Unmanned Aerial Vehicle) LiDAR archaeology technology, they received impressive results. They also made some new discoveries." The team created a high-resolution terrain model of the Sand Canyon Pueblo site. The article describes the six mission steps of planning, data acquisition, Quality Assurance (QA), data download, data processing, and final outputs. They surveyed the area with UAV-based LiDAR. They had to ensure sufficient line-of-sight for flying the UAV. They noted that ground targets are a must for drone-based LiDAR surveys. They also noted some density-altitude considerations because of the altitudes of the archeology sites. It was indicated that they may need to return to collect more data – a true mark of research.

Miller (2019b) describes, in "Federal UAS program offers potential beyond fighting wildfires", the legislation passed by Congress to establish a federal program to integrate UAS technology into wildfire-fighting operations. It "has the potential to create even more opportunities for drones". A focus of this act is to promote research. "The Natural Resources Management Act passed by Congress includes a provision establishing a research, development and testing program to assess UAS technologies for wildland fire management operations." The article provides an overview of potential positive impacts.

Research – Development. "Terra Drone Continues to Expand its Global Footprint: Introducing Terra Drone Ventus in North America" (McNabbon 2019d) discusses Terra Drone joining a gas and oil inspection company to form a new entity in North America that combines the capabilities of gas detection sensors, high endurance drones, and proprietary systems that can perform wall-thickness measurements for the oil and gas industry.

In an interesting mix of technologies, "Cranfield University researchers in England are unleashing a smartphone app that connects off-the-shelf drones and allows them to be sent autonomously to inspect multiple locations using coordinates received by text messages" (Reaganon 2019b). "The goal of the CASCADE project is to accelerate the exploitation of unmanned aerial vehicles (UAVs) across a range of science and industry applications by automating control and facilitating communication between multiple drones so they can work on tasks together." The system "receives waypoints via text message, compiles the mission and sends standard off-the-shelf (commercially available to the general public) drones on autonomous missions with no user intervention required. Safety features are included within the app to ensure the drone operates within legal requirements, and currently a safety pilot is required to keep the drone within line of sight throughout the mission."

From a safety standpoint, Murisonon (2019b) discusses the partnering of two companies that are now combining off-the-shelf drones with parachute products. Looking toward automated operations, there is a move toward greater independence and automation for drone applications referred to as "Unattended Technology" (DroneLife 2019). "Unattended technologies are those that facilitate the use of automated drones to perform tasks—not just the automation technology that allows the drone to perform its mission, but technology that allows the drone to charge its own battery." The article provides an overview of technologies, advances, and information about some specific systems.

Murisonon (2019c), "SKYCORP Doubles Standard Flight Time with New Hydrogen Drone", is a good example of a development effort. They claim to double "the maximum flight time of its hydrogen-powered e-Drone Zero. The commercial drone can now fly for two hours with help from a new, ultra-lightweight gas cylinder from AMS Composite Cylinders." The focus is on flight endurance.

Schmidt (2019) discusses how photogrammetry will replace LiDAR in transmission-line inspections. "FAA urged to approve drone delivery" (Murphy 2019b) provides various examples for drone delivery. The thrust of the article is a strong argument for the FAA to push this technology forward. DBUS2 is the first consumer drone equipped with Visual Inertial Odometry (VIO), a new technology that enables drones to navigate on their own without human input (Miller 2019c). The system uses a camera for odometry, inertial motion sensors, and software to recognize object shapes and determine the drone's location. They claim that "VIO enables DBUS2 to hover accurately within plus or minus 3.8 inches".

Research – General. The UAS Magazine (2019a) article "ND establishes first ever UAS super corridor for BVLOS" details the announcement of the 100-mile super corridor established in North Dakota for BVLOS operations. This can be classified as an academic or development application as well as one that fosters general research. "The new super corridor utilizes an unprecedented and advanced network of radar, communications and sensors. Chase planes, currently required for BVLOS flights in the U.S., will not be required within the super corridor." Details of the corridor, operations, and support infrastructure are included.

Research – Market. "Heisha is betting that there are plenty of potential customers who need aerial data – but don't want to fly a drone" (DroneLife 2019). "The complete solution is for an outdoor, private property live stream: anytime, anywhere, and without a pilot certificate. The system is completely unmanned: and both live video and the drone can be controlled from a mobile phone. With just one mobile app, users can control the drone to take off and take a quick shot from wherever they are. The S300 includes an auto-charging pad, a drone, a cloud service system, modified landing gear and battery, an optional rain-proof canopy, and a nest-shaped base. The complete solution costs just $1,999, making the system a cost-effective system for almost anyone. For example, agronomists can optimize their day on the farm by taking an aerial survey over fields via cell phones and sharing the video and info with staff."

Research – Operations. Without expanding this use case to capture every possibility, a good example of research related to operations is the A18 ASSURE COE (Center of Excellence) research effort for the FAA. Elements of this are academic and developmental in nature, and other elements involve product testing as well. The other portion is directly related to how to operationally integrate and fly the systems.

Research – Product Testing. A number of different product-testing application use cases have been noted above. These include the use of parachutes on UAS for safety (Murisonon 2019b) and boiler inspections (Reaganon 2019a).

In "US-1 Quadcopter Crosses Nevada Desert in One Charge", Lillian (2019c) describes a 72-minute flight operation in early August. "The aircraft used for the flight was an unmodified-production US-1, carrying both a FLIR Duo Pro R camera and HD video transmitter. With and against the prevailing winds, the US-1 flew distances of 29 and 21 miles, respectively." This is an Excellent example of product testing. "The ultimate vision of Impossible Aerospace is to build long-range electric aircraft that carry goods and people around the world, emissions-free …".

The NASA (National Aeronautics and Space Administration) testing of UAVs in Reno (Cook 2019) details how NASA tested avoidance capabilities and other features of its UTM. "NASA had tested the UTM in rural locations, but this was the first opportunity to see how it worked in an urban environment, where the potential conflicts are greater and the challenges of controlling the UAV's path among buildings and other obstructions are significantly greater."

Research – Transportation. The Murphy (2019b) article cited above provides an argument for pushing technology forward in relation to drone delivery. The various examples provided focus on the elements related toward transportation research.

Search/Rescue. The use of drones for search/rescue is one of the few use cases that is not driven purely by economic forces. Some cost savings are possible depending upon which assets can be used to replace more expensive assets, but the most significant driver is humanitarian. These are harder to quantify from an economic standpoint but are extremely important. The user communities who would employ these assets are highly motivated to adopt these technologies, and society is benefiting from these uses.

In "County in Sierra finds search and rescue uses for drones", Pearce (2019) describes the system used. The drone was equipped with camera and heat imaging. It was able to search from the air when those below are unable. "We use it during the hasty search period when we don't have other manned aircraft in the air space," says Deputy Sheriff Jake Krzaczek, "and we can also use it to search at night, which previously we were reluctant to do because it puts our volunteers in harm's way." Applications and operations are described where the UAS is used to drop food, water, a radio, and extra clothing. In a novel use, a drop bag with a rescue line is dropped for someone trapped by a river who needs to be safely transported to the other side.

UAS Magazine (2019b) describes a drone designed specifically for search and rescue missions. The Swiss company is aiming to deploy the aircraft, likely in 2020, on missions to search for missing, injured, or ill persons in advance of manned helicopter or ground rescue operations. The system is capable of BVLOS operations. The aircraft is equipped with various sensors including a thermal camera. A self-learning algorithm to improve the searches is notable. The system also employs a mobile phone tracking function. From discussions with industry, the use of mobile device interconnectivity, operation, and tracking will expand in the years to come.

Search and rescue are often thought of in terms of people in need. The search portion may actually be for both individuals who want to be found and those who do not. Gearty (2019), in an article titled "China police nab fugitive on lam for 17 years after drone discovers cave hideout", describes how police used a UAS to locate someone who did not want to be found. "Search police drones spotted a blue-colored steel tile on a steep cliff and household trash that was strewn nearby, according to the BBC," These telltale signs led to capture and arrest.

5.2.1.2.3.11 Surveillance, Monitoring, etc.

Monitoring – Environmental. If there is one area that demonstrated the most significant change over the past few years with a positive increase of use cases, it is environmental monitoring. Drones are a new, maturing, and effective tool being used by a very wide variety of interest groups. Like many of the applications noted in this document, the uses cross a number of areas. Most of these operations are truly trying to make the world a better place.

The Strochlic (2017) article paints a broad portrait of the "surprising ways drones are saving lives", and highlights vulture monitoring, fighting poachers, and more. "Drones Are Helping Catch Poachers Operating Under Cover of Darkness" (Worland 2018) highlights that "[e]ighty percent of poaching happens under the cover of darkness." In Africa, night vision systems are being used, and are coupled with artificial intelligence systems to improve operations.

One of the most detailed and practical articles cited in this document is "7 Top Anti-Poaching Drones for Critical Wildlife Protection" by Corrigan (2020). "Anti-poaching drones are making a big impact in the saving of Rhinos, Elephants, Tigers, Gorillas and other critically endangered species." The author notes that illegal wildlife trade is worth $4.5 billion annually. This is a huge problem.

The broad categories of uses include drones to count, protect, and manage endangered species and habitat. As stated by Corrigan (2020), "Together with poaching, the deforestation and the destruction of rainforest and grasslands also cause species to become endangered. Fixed wind [sic] drones cover large land mass and are playing a big part in the reduction of illegal destruction of habits in nature reserves and parks." The article provides a laundry list of potential use cases. "Along with anti-poaching activities, drones can fulfill all the following conservation tasks.

- Animal/flock counting
- Camera trap image retrieval
- Vessel monitoring (e.g., whaling ships)
- Animal tracking (e.g., via radio tracker collars/triangulation)
- Migration tracking
- Perimeter assessment
- Habitat management
- Anti-poaching activities (identification, deterrence)
- Nest surveys
- Species identification"

The interaction between anti-poaching drones and ground forces is discussed. This continuity and follow-through are important. Other topics addressed include drones with sensors, predictive analytics and pattern recognition, predictive analysis, and what is needed in a mobile command center. Detailed description and specifications for seven specific aircraft are provided. With each aircraft, sample anti-poaching missions are detailed in many locations, including Zimbabwe, Malawi, South Africa, Tanzania, Namibia, locations in South America, Suriname, Sumatra, Canada, the United States, and more. This article was one of the most comprehensive end-to-end use case descriptions found.

One more use case of note is conservation through the attempted elimination of an invasive species. In "Drones dispense rat poison to help rid islands in Galapagos region of rodents", (Dormehl 2019) details an innovative approach to reach inaccessible areas to address a problem. "The North Seymour region in question had been rat-free for more than a decade when two species of rat were detected last year. These rats eat the eggs and babies of local seabirds, as well as damage plants and trees by gnawing on them and eating their seeds." The solution "used two six-rotor drone copters to spread bait laced with rat poison around the islands. Previously, this has been achieved using helicopters, but drones were concluded to be a cheaper method of carrying out the task. A flying vehicle is necessary for this job due to the rugged local terrain, which makes it tough to do by hand. Each drone is able to carry up to 20 kilos of bait for a flight time of 15 minutes."

Monitoring – General. Many of the use cases that fit within this category of monitoring are not stand-alone use cases. They fit into some of the more specific areas noted throughout this document. In "FlyTech UAV Upgrades Fixed-Wing Surveying Drone with VTOL Capability", Ball (2019) describes the BIRDIE system— "BIRDIE fixed-wing UAS with VTOL (vertical takeoff and landing) capabilities." BIRDIE is billed as "a complete mapping solution consisting of the fixed-wing platform, dedicated flight controller, PPK, full-frame camera and GSM connectivity for unlimited flight range." For both fixed-wing and VTOL flight, they claim a mapping accuracy up to 3 cm and resolution up to 1 cm/px can be achieved. While the markets for this system are quite broad, it can be used for a number of different monitoring applications.

Monitoring – Legal. Use cases that include applications for legal purposes exist and include gathering of evidence and legal aid. Both police/law enforcement groups and private commercial companies use UAS for legal-related use cases. UAS are used for providing aerial video and photographic documentation of any outdoor crime scene, arson, catastrophic damage event, vehicle crash reconstruction, and more. Imaging is used to generate both 3D and CAD (Computer-Aided Design) reproductions of the scenes that can be used in court. A good example of this application is in "Drones Used to Map Crime Scene" (Unmanned Systems News 2019). In addition, a few lawyers advertise that they are experts in "drone law, and drone attorney assistance".

Monitoring – Safety. Monitoring for safety comes in a few different forms. As noted above (Knight 2018), drones can be used to detect radiation. The two articles by Flyability (2019a, b) describe the use of drones for mapping of mines and indoor spaces—both highlight safety-related elements. It is noted that use for safety is widespread, as indicated by AUVSI (2019a): "DroneResponders, a non-profit program that supports public safety UAS, has announced that it has surpassed 600 member public safety agencies that are operating UAS". In this, at least 25 different countries are represented. They plan to launch a "Fall 2019 Public Safety UAS research survey". The goal of the survey is to explore the user space. "While that group is united under the flag of public safety, the fact is that law enforcement, fire rescue personnel, and search teams often have different use cases and needs for their drone operations. We want to drill down into those subsets and uncover their trends and needs."

Jacobson (2019), in "Met to become first UK force to deploy drone to monitor road users", notes that the police describe how "UAV will focus on road users engaged in dangerous driving such as racing." The article touches on both the earlier use in France and this latest adoption in the UK. "In France, police have been using drones since 2017 to catch vehicles driving dangerously, such as trucks that are tailgating other vehicles or motorists who illegally overtake. Police in Bordeaux catch up to 20 vehicles an hour, issuing them with on-the-spot fines." "The Metropolitan police will become the first British force to deploy a drone to monitor road users" in late July. "The unmanned aerial vehicle will focus on road users engaged in dangerous driving, such as racing, that could potentially put others at risk, rather than targeting all speeding motorists, according to the Met. Once a suspect has been spotted, information will be relayed from the drone to officers further along the road so they can pull them over. The drone has a night vision function and will be able to operate at both high and low altitudes."

If there is a challenge and UAS can be used as for a novel and unique solution, then that is where many of the new/revised use cases come from. For instance, drones have been used to spot sharks near swimmers at the beach. These press reports have become regular and usually feature an image of an unwary swimmer or surfer with a shark in the same image nearby. There is no reason this technology cannot be used for other analogous activities. In "Little Ripper deploys croc-spotting AI drones", Chanthadavong (2019) describes how this technology has been "repurposed" for spotting crocodiles. The goal is to help keep beachgoers safe from crocodiles in the water and on land. "The same artificial intelligence (AI) drone technology that the Little Ripper Group used for its shark detection drones is now being used to spot crocodiles in Queensland. The drone technology, dubbed the Little Ripper and designed together with the University of Technology Sydney, uses an AI system that was originally designed to detect sharks in real-time."

"Speaking at the Amazon Web Services (AWS) Public Sector Summit in Canberra on Wednesday, Scully-Power said the drone technology can differentiate up to 16 different types of marine life." There is no listing of which types can be identified, but this is a good demonstration of just how the technology can be adapted. As added functionality, "the technology also features an in-built siren and speaker system and can also deploy flotation pods during emergency rescues to support up to four people". The article notes that "last summer, 51 drones were deployed around Australia to help spot rips and swimmers in distress." Much of the same material is also noted in the article "Amazon helps deliver crocodile-spotting drones in Australia" (Lee 2019).

Murphy (2019c) highlights how the industry is, in some ways, responding to the market and safety desires. DJI plans to install AirSense ADS-B on all 250 g or larger drones by 1 January 2020. In a related piece, DJI released a 37-page white paper, "Elevating Safety," that outlines a 10-point plan for execution.

Monitoring – Security. Security and safety can sometimes go hand-in-hand. A number of use cases cross over into both areas. A Robotics Tomorrow (2019a) article describes an extended range, endurance, and payload capacity for a sUAS. The advances are supported through "proprietary battery chemistry, incorporated in purpose-built cell designs, with demonstrated flight times exceeding 50 minutes and organic ISR capability (thermal and 5MP E/O video) sensors. The system provides either the Tactical Standoff (640 x 480 thermal and 4x E/O) or Close Area Target Reconnaissance (10X E/O) payloads in its ISR configuration. This capability allows the user to continuously observe named areas of interest, prosecute fire missions, and actionably influence wide (>100 km^2) areas of the battlespace, day or night, from a rucksack, without relying on low density, high demand, and high cost assets."

Another Robotics Tomorrow (April 2018) article describes the introduction of a new group 1 VTOL sUAS that employs tactical Intelligence, Surveillance, and Reconnaissance (ISR). "The SkyRaider carries a suite of long-range, high-resolution, stabilized daylight and IR imaging payloads. These are supplemented with a front-mounted EO/IR payload for day and night situational awareness and secondary view-angle ISR when carrying non-optical payloads." A goal is to enable persistent over watch. It has a dark mode: "… when missions call for operation in denied RF environments, Dark Mode enables semi-autonomous flight plans without an active C2 link. This enables applications such as beyond visual line of sight (BVLOS) payload emplacement and clandestine ISR in non-permissive environments. GPS Zeroize ensures that no sensitive information falls into enemy hands. With GPS Zeroize turned on, no location records are stored, and no video is recorded on the aircraft."

With the ongoing trend and desire for smaller systems, Pickrell (2019) details this push in "US soldiers in Afghanistan are patrolling like never before with these awesome pocket-sized spy drones". These "personal reconnaissance drones" improve situational awareness and provide high quality images and video. "US Army soldiers with the 3rd Brigade Combat Team, 82nd Airborne Division deployed to Afghanistan last month with Black Hornet personal reconnaissance drones, game-changing technology that offers greatly-improved battlefield situational awareness at the squad level. Soldiers have already begun patrolling parts of Afghanistan with these lightweight unmanned aerial vehicles — tiny helicopters measuring only about 6 inches in length and weighing just 1.16 ounces. Members of the 3rd BCT have previously described this technology as a "life-saver" for US troops operating in combat zones."

Security support using UAS for sporting events has expanded. As noted above (AUVSI News 2019a), UAS were used as part of security efforts for the Copa America soccer tournament. UAS use at the most recent Super Bowl (Moore 2019) also highlights utility for providing security over watch and providing "thermal and visual images to the public safety command centers". Radar systems (by Fortem Technologies) were used for detection, and a trio of drone-hunting were used on patrols.

Another security-related effort where drones are used is in and around prisons. Almost weekly there are reports of contraband being dropped into prisons. In "Prisons enlist drones to monitor inmates, grounds", Leonard (2018) reports that the "South Carolina Department of Corrections announced it will use drones to keep an eye on inmates and prison property. The drones will be outfitted with high-resolution cameras as well as heat-sensing and night-vision capabilities to monitor attempts to bring contraband into the prison and watch for fights within the prison walls."

5.2.1.2.3.12 Other UAS Applications

Some applications are difficult to fit into the taxonomy detailed above. Many use cases span multiple categories. A few use cases that are unique or novel. This section is added to the taxonomy as a catch-all. One potential new use case area is for "Outdoor and Recreation". People fly for fun. People also adapt technologies for other uses. In a novel recreational sUAS use case, Bartiromo (2019) documents how a fisherman used a sUAS to carry his baited hook well offshore and drop it in the water. The angler was tarpon fishing and had used a technique "they learned from an Australian fisherman who developed the process". He ended up catching a 110-120 lb. tarpon.

Not germane to a specific category or set of categories, the use of more than one drone to accomplish an effort has been proposed. Use of multiple UAS has received increasing attention, especially in research and testing. While swarm technologies involve a very large number of aircraft, use of two or more at a time is also being discussed for potentially supporting some efforts.

5.2.1.2.4 <u>UAS Industry</u>

One means of broadly dividing UAS use cases is according to benefits toward the public good and those that can be monetized. In some cases, both the public good and providing a better cost-effective solution are not mutually exclusive. It is clear from the use cases identified that much is being done to further the public good, and the industry is growing because excellent solutions can produce profits. The Danish Technological Institute (DTI) and AUVSI (2019b) published "Global Trends of Unmanned Aerial Systems," an excellent resource that captured a snapshot of the state of industry in 2019.Earlier this year, the Danish Technological Institute (DTI) and AUVSI (2019b) published "Global Trends of Unmanned Aerial Systems". This is an excellent resource that captures a snapshot of the state of the industry.

Miller (March 2019d) provided an excellent summary of the DTI and AUVSI report in "Report: UAS industry shows exponential growth since 2016". It looks at the industry growth as reported and summarizes it in a few salient points.

- The report found that 80% of patents associated with UAS technologies have been published since 2016.
- The U.S. has developed 628 unique drone platforms, followed by China with 309, and France with 114. These conclusions are based upon an analysis of data from AUVSI's Unmanned Systems and Robotics Database.
- Other findings from the report, which provides a snapshot of the capabilities and technological specifications of UAS, include:
  - Nearly 80% of the 2,185 platforms analyzed are used in the civil market, while 65% are used for commercial purposes.
  - Roughly half of the platforms analyzed can be used for precision agriculture purposes, such as monitoring crop health and irrigation.
  - Nearly 1,350 of the platforms analyzed can assist in search and rescue operations after natural disasters. These UAS have greater than average speed and endurance capabilities that help improve the success of their searches for survivors.

Again, this report is just a snapshot in time of this ever-changing and -evolving industry; the applications and use cases are only limited by the imagination of the users.

5.2.1.2.5 Assessment of Use Cases for BVLOS and DAA

A review of all potential types of use cases was completed. This was an application focused collection, and they were broken down into general use area. The potential sUAS use cases gathered were then assessed to see if they were prospective BVLOS type applications that would use DAA approaches. If an operation is to fly BVLOS then the need for DAA is considered high. Not all uses cases or applications require BVLOS flights. Having a DAA system as part of any operation obviously enhances safety. An attempt at a top-level classification of the use cases based on the need for DAA is presented in

Table 8. This is based upon a review of the use cases, information gained through work with NMSU Flight Test Site users, and discussions with members of the UAS industry.

Table 8 presents the general top level "Application Area" and the next level breakdowns within that area including specific "Applications". These individual applications were then assessed if it was a likely candidate for BVLOS flights. Again, all flights and applications are not BVLOS type flights. The "BVLOS Application" column presented a rough grading of the potential toward being a BVLOS type flight. Applications vary by individual case so there are few hard lines on the use cases. The subjective grading includes the following

- Likely No – The need for these applications to fly BVLOS type missions has been assessed to be low. Operations are generally within set limited areas. Inspection of a transmission tower is a good example of a closely defined limited area where the pilot has LOS (Line of Sight) for the entire flight. A construction site is also likely to be a defined area where LOS flights can accomplish the entire inspection mission, but there may be some very limited cases where the site is large enough that BVLOS flights may be required.
- Situation Dependent – These cases present a range of use case applications where the range of types of operations is too broad to say if BVLOS flights are required. Crop monitoring may be for a single small plot of land like and orchard (LOS operation) or very large tracts of cultivated land (BVLOS operation). Mapping for construction could be for a building site (LOS) or for a pipeline (BVLOS). The individual missions define the flight type and if they are LOS or BVLOS.
- Yes – There are a few applications that by nature of the mission will be BVLOS, e.g., Inspection of long linear infrastructure and long-distance transportation in any form.

A "DAA Need Assessment" was then completed based on reviewing the inputs for the individual applications. All of the various potential use cases noted above have the potential need to fly BVLOS and could benefit from incorporation of a DAA system. Not all use cases have the same level of need to fly BVLOS or will be operated in potentially complex spaces where DAA would be as much of a benefit. An example is closed set filming. The closed set implies a controlled flight environment where a DAA system may not be needed, but there could be a need for long extended camera shots that would require BVLOS operations. There is a spectrum of applications that may require DAA, not be needed at all, or have a need somewhere in between. The level of DAA system required may also vary by application, geography, flight location, operational parameters, etc. This initial assessment of the various use cases evaluates each use case for BVLOS types of operations and then relative need for implementing a DAA system. In all cases, the specific application should be used to determine the need for using a DAA system. As stated above, using a DAA system should enhance safety. The following assessment guidelines were used.

- N/A or Low – Very limited flight altitude and/or areas with LOS flights would likely not require a DAA system. Tower inspection or capturing "real estate" images are examples.

- Low – Flight operations where there is a potential for the need for a DAA system. Again, this is situationally dependent. Flight to assess damage for insurance purposes in limited areas is an example.
- Medium – Flight operations where there is an identified increased need for a DAA system. Again, this is situationally dependent. Precision agriculture where flights are over larger areas and for extended durations is an example where there may be an increased need for a DAA system.
- High – If the operation is BVLOS or if there are known applications where other air assets are in the area (e.g., Search and Rescue or Crisis Response), then the need for a DAA system is high.

This assessment is subjective since specific use cases vary. Again, as noted above, the DAA needs assessment was based upon a review of the individual use cases gathered that formed the top-level application areas, information gained through work with NMSU Flight Test Site users, and discussions with members of the UAS industry.

Table 8 is intended as a guide and not a definitive list of DAA needs.

Table 8. Use case applications—BVLOS and DAA application assessment.

Application Area	Application	BVLOS Application	DAA Need Assessment
Aerial Data Collection	Aerial Data Collection - Construction/Mining	Situation Dependent	Low
	Aerial Data Collection - Environmental	Situation Dependent	Medium
	Aerial Data Collection - General	Situation Dependent	Low
	Aerial Data Collection - Insurance	Situation Dependent	Low
Aerial Photography/ Videography	Aerial Photography/Videography - Closed-set filming	Likely No	N/A or Low
	Aerial Photography/Videography - Construction	Likely No	N/A or Low
	Aerial Photography/Videography - General	Likely No	N/A or Low
	Aerial Photography/Videography - News-Gathering	Likely No	N/A or Low
	Aerial Photography/Videography - Outdoor Activities	Likely No	N/A or Low
	Aerial Photography/Videography - Real Estate	Likely No	N/A or Low
	Aerial Photography/Videography - Wedding	Likely No	N/A or Low
Aerial Surveying/ Mapping	Aerial Surveying/Mapping - Agriculture/Mining	Situation Dependent	Medium
	Aerial Surveying/Mapping - Construction	Situation Dependent	Medium
	Aerial Surveying/Mapping - Engineering	Situation Dependent	Medium
	Aerial Surveying/Mapping - General	Situation Dependent	Low
Agriculture	Agriculture - Crop Monitoring	Situation Dependent	Medium
	Agriculture - General	Situation Dependent	Low
	Agriculture - Precision Agriculture	Situation Dependent	Medium
Emergency Services	Emergency Services - Crisis Response	Situation Dependent	High
	Emergency Services - General	Situation Dependent	Medium
	Emergency Services - Investigate Hazardous Regions	Situation Dependent	High
Flight Training/ Education	Flight Training/Education - Education	Likely No	Low
	Flight Training/Education - General	Situation Dependent	Low
	Flight Training/Education - sUAS Training	Situation Dependent	Medium
Inspection	Inspection - Communications Structures	Likely No	N/A or Low
	Inspection - Construction	Likely No	N/A or Low
	Inspection - General	Likely No	N/A or Low
	Inspection - Insurance	Likely No	Low
	Inspection - Oil/Pipeline	Yes	High
	Inspection - Power plants	Situation Dependent	Medium
	Inspection - Real Estate	Likely No	N/A or Low
	Inspection - Structure	Situation Dependent	Low
	Inspection - Wind power	Situation Dependent	Low
Marketing	Marketing - Aerial Images	Likely No	N/A or Low
	Marketing - General	Likely No	N/A or Low
Multiple Applications		Situation Dependent	Low
Research	Research - Academics	Situation Dependent	Low
	Research - Development	Situation Dependent	Medium
	Research - General	Likely No	Low
	Research - Market	Likely No	N/A or Low
	Research - Operations	Situation Dependent	Medium
	Research - Product Testing	Situation Dependent	Medium
	Research - Transportation	Yes	High
Search/Rescue		Yes	High
Surveillance, Monitoring, etc.	Monitoring - Environmental	Situation Dependent	Medium
	Monitoring - General	Situation Dependent	Low
	Monitoring - Legal	Situation Dependent	Low
	Monitoring - Safety	Situation Dependent	Low
	Monitoring - Security	Situation Dependent	Low
Other UAS Applications	Novel or unique use cases	Situation Dependent	Medium

5.2.2 Further CONOPS Considerations

Results from A2 and A18 provide tremendous granularity for some classes of CONOPS. However, not all CONOPS (e.g., package delivery) are captured. In order to provide a higher-level view of CONOPS, a classification that has been presented by the FAA is leveraged (
Figure 12). The results from A2 and A18 illustrate very specific CONOPS that generally align with Operations Over People, Expanded Operations, Non-Segregated Operations, and Routine/Scheduled Operations in
Figure 12. The A2 and A18 CONOPS, of course, do not all correspond to all of these categories in
Figure 12.

Figure 12, though, highlights some other CONOPS classes that are of critical importance: Small UAS Package Delivery Operations, Large Carrier Cargo Operations, and Passenger Transport Operations. The focus herein is on sUAS and, thus, on the elements in
Figure 12 up through Routine/Scheduled Operations.

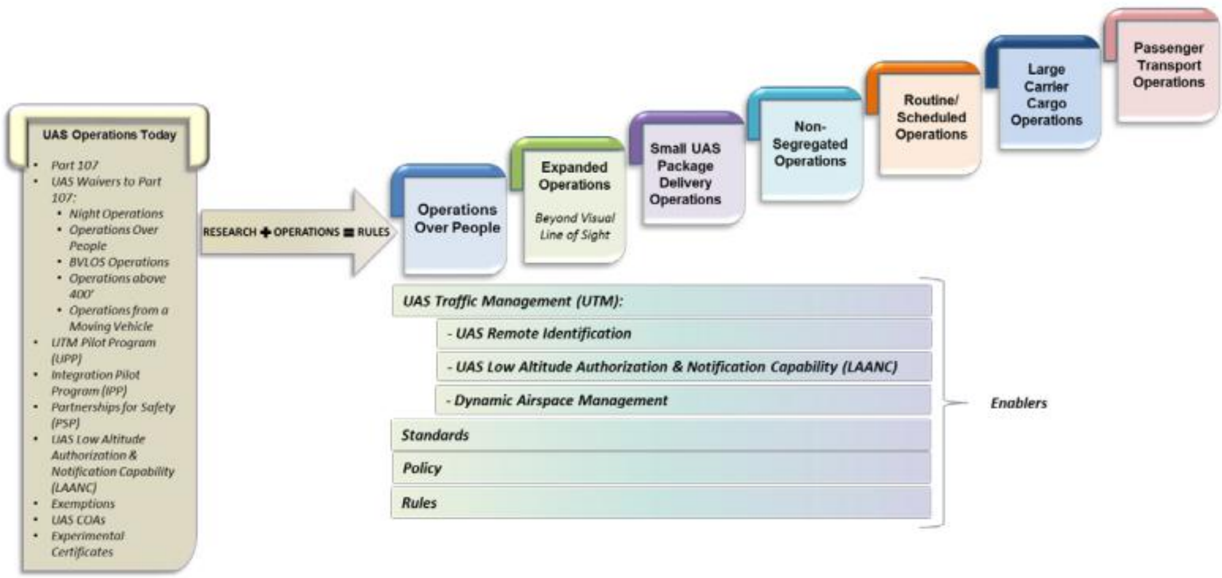


Figure 12. Illustration of CONOPS, current UAS Operations, and enablers. From Strande (2019).

5.2.3 CONOPS Summary

5.2.3.1 CONOPS Characteristics

A CONOP generally describes the characteristics of an operation. While CONOPS can be organized in different ways, insight into elements of CONOPS can be acquired by considering types of data that are proposed to be collected for the CONOPS phase of the proposed test data collection system designed in another ASSURE project: A11L.UAS.50 (Phase I) – UAS Test Data Collection and Analysis Phase I (referred to as A19 Phase I). These categories are:

- System Information (what)
- Aircraft Procedures (how)
- Crew Members (who and how)
- Operational Scenario Description (why, who, and when)
- Operational Considerations—Ground Based (where)
- Operational Considerations—Airspace (where)
- Meteorological Conditions (where)
- Communications (how)
- Security (how)

These have been labelled with the 5 w's and 1 h (who, what, where, when, why, and how). A CONOP should answer these and should describe, in detail, all of the aspects of an operation.

The CONOPS considered herein encapsulate a dizzying degree of possible variations in the 5 w's and 1 h. They have been organized, generally, according to "what" (the mission). Despite these variations, some common characteristics are present, as described in the following sections.

5.2.3.1.1 Who

As described in Sections 5.2.1 and 0, numerous entities can execute a CONOPS. Moreover, multiple types of entities can be involved (e.g., public, and industry/private). The following are the types of operators that are understood to be the typical operators, based upon CONOPS information gathering, for CONOPS/application areas:

- Aerial Data Collection: Industry; Public—Federal, State, and Local (environmental subcategory)
- Aerial Photography/Videography: Industry
- Aerial Surveying/Mapping: Industry; Public—Federal, State, and Local (general subcategory); Hobby/Recreation
- Agriculture: Industry
- Emergency Services: Public—Local, State, and Federal, Industry (through contracts)
- Flight Training/Education: Public—State; Industry
- Inspection: Industry
- Marketing: Industry
- Multiple Applications: Industry and Public
- Research: Public—Federal and State; Industry
- Search/Rescue: Public—Local, State, and Federal; Industry (through contracts)
- Surveillance, Monitoring, etc.: Public—Federal, State, and Local; Industry (general, safety, and security subcategories)
- Small UAS Package Delivery Operations: Industry
- Large Carrier Cargo Operations: Industry
- Passenger Transport Operations: Industry
- Other UAS Applications: Industry, Public, Hobby/Recreation

5.2.3.1.2 What

These are discussed in the preceding sections and provided in the preceding list.

5.2.3.1.3 Where

Flight locations for some CONOPS are driven by:

- Specific mission sets within them: Specific Research missions
- Associated activity: Construction (for example)
- Items for which data are collected: Aerial Data Collection, Aerial Photography/Videography, Aerial Surveying/Mapping, Agriculture, Inspection, Marketing, and Surveillance
- Existing resources/institutions: Flight Training/Education
- Economic considerations: Passenger Transport Operations (urban) and Small UAS Package Delivery Operations (urban/suburban)

Numerous CONOPS could be executed nearly anywhere (e.g., Aerial Data Collection and Research), while others are unlikely in locations such as remote areas of large water bodies but quite possible elsewhere (e.g., Aerial Photography/Videography, Aerial Surveying/Mapping, Marketing, Research, and Surveillance). Currently, operations tend to occur in the most permissive airspace (e.g., Class G per Part 107). However, as the "Non-Model Unmanned Aircraft Customer Satisfaction Survey" results compiled in 2018 (D. Bhadra and M. Lukacs, personal communication, 22 December 2020) indicate, all types of airspace are utilized, in the order G, E, D, C, B, and A. This survey also indicates that flights are generally conducted at altitudes less than 400 ft. This is strongly driven by ease of access (Part 107). As UAS become more integrated, more operations will occur at higher altitudes because of its enablement of efficient data collection over a relatively large region (e.g., Aerial Surveying/Mapping, Agriculture, Aerial Data Collection, and Surveillance) or necessity for the CONOP (e.g., Large Carrier Cargo Operations).

5.2.3.1.4 When

While some CONOPS are definitely driven by time of day (e.g., daytime collection for Aerial Photography/Videography and Marketing), many CONOPS could be executed at any time of the day in order to accomplish the desired missions. Other factors may impact operations, such as hazards (lighting, diurnal weather phenomena, etc.). In addition, some missions will be driven by season (e.g., Research missions involving seasonal phenomena). Currently, many missions are operated during the day because of Part 107 regulations, although nighttime waivers are the most successful type of Part 107 waiver.

5.2.3.1.5 Why

The specific reasons for utilizing UA vary greatly across CONOPS and can be understood by examination of the preceding discussions of specific CONOPS. The motivations for utilizing UA can, however, be broadly categorized according to:

- Humanitarian: This driver is about saving lives, mitigating injuries, etc. The primary CONOPS that are driven by this motivation are Emergency Services and Search/Rescue. However, any enhancement of safety can be considered to be motivated, at least in part, by humanitarian concerns.
- Safety: One of the greatest benefits of unmanned/autonomous systems is they commonly enhance safety. The benefits of this are both mitigation of fatalities/injuries (humanitarian) and cost savings. While information to evaluate the degree to which enhanced safety motivated the CONOPS listed above is not available, the A21 team recognizes that enhanced safety is a primary motivated in many of the CONOPS, including Aerial Data Collection, Aerial Photography/Videography, Aerial Surveying/Mapping, Agriculture, Inspection, and Surveillance, Monitoring, etc.
- Cost: Cost savings/efficiency is a fundamental driver of use of UAS. Except for those missions that are primarily motivated by humanitarian concerns, cost is a principal motivator owing to either market opportunities, savings owing to safety enhancements, or both.

5.2.3.1.6 How

The primary division between types of operations is LOS/BVLOS. Other expanded and non-segregated operations that have been delineated using high-level hazards are operations over people and operations over moving vehicles (cf. Section 5.4**Error! Reference source not found.**). These capabilities are nearly a requirement for BVLOS operations and are enabling for LOS operations. Using LOS/BVLOS as the primary divider, the system used to execute a mission is driven by its endurance and its requirement for supporting technologies (DAA, C2, enhanced airworthiness and mitigations for loss of controlled flight, etc.). BVLOS missions will generally be better supported by fixed-wing aircraft while LOS missions are dominated by rotary-wing aircraft. As propulsion technologies advance, more rotary-wing aircraft will be leveraged for BVLOS operations. In addition, larger and heavier UAS will be utilized as collision hazards are better mitigated since they generally enhance mission objectives. The culmination of these trends includes the very challenging CONOPS Large Carrier Cargo Operations and Passenger Transport Operations.

5.2.3.2 CONOPS Importance

The term 'importance' can be interpreted both as an indication of intrinsic value and as an indication of activity. The former interpretation would arguably place the Emergency Services and Search/Rescue CONOPS at the top of the list owing to their humanitarian impacts. The latter interpretation can provide insight into current and future UAS demand. While information in this regard is limited, the "Non-Model Unmanned Aircraft Customer Satisfaction Survey" results compiled in 2018 (D. Bhadra and M. Lukacs, personal communication, 22 December 2020) provide the following ranking:

- R&D/Training/Education: 21%
- Film/Event/Entertainment/Sports: 21%

- Industrial/Utility/Oil & Gas: 16%
- Real Estate: 13%
- Construction: 8%
- Agriculture: 7%
- Other: 6%
- Press and Media: 5%
- Emergency and Preparedness: 3%

While these categories do not correspond with the categories utilized herein, this list provides insight into where UAS utilization is currently focused. Relative to the categories utilized herein, the ranking becomes:

- Research and Flight Training/Education
- Aerial Photography/Videography (closed-set filming, general, outdoor activities)
- Aerial Data Collection (mining, general), Aerial Surveying/Mapping (engineering, general), and Inspection (communication structures, general, oil/pipeline, power plants, structure, wind power)
- Aerial Photography/Videography (real estate) and Inspection (real estate)
- Aerial Data Collection (construction), Aerial Photography/Videography (construction), Aerial Surveying/Mapping (construction), and Inspection (construction)
- Agriculture and Aerial Surveying/Mapping (agriculture)
- Aerial Photography/Videography (news gathering)
- Emergency Services and Search/Rescue

It is noted that these rankings are driven by both demand for capabilities and ability to operate. As UAS integration advances, it is expected that these rankings will change.

5.3 Data Required for CONOPS Evaluation

5.3.1 Rejected Part 107 Waiver Analysis

The A21 team requested the rejected Part 107 waivers. However, the request was not granted. Thus, the A21 team worked with project sponsors to develop an understanding of characteristics of rejected Part 107 waiver requests. An illustration of the proportion of approved versus rejected waivers is provided in Figure 13. As this figure shows, the vast majority of waivers are rejected.

Part 107 waivers are rejected because, in a simple sense, the associated safety cases are insufficient. A trend analysis has been completed for both 107.31 (BVLOS) waivers and 107.39 (Operations over People) waivers (FAA, 2020c). This analysis identifies the following deficiencies for these types of waiver applications:

- BVLOS
    - Command and Control (C2): Lacking operational data (e.g., operating range) and/or Federal Communications Commission (FCC) approval
    - DAA: Lack of information regarding methods or procedures and performance for DAA
    - Operational Limitations: Lack of information regarding how environmental hazards would be mitigated
    - Crew: Lack of information regarding crew qualifications (who has what training) and how the training of the crew is assured
- Operations Over People
    - Ground Collision Severity: Test data that were not for the sUAS to be used were provided or calculations (estimates) were provided instead of test data.
    - Laceration Injuries: Test data that were not for the sUAS to be used were provided or statements indicating propeller guards would be used without supporting test data as their efficacy or no information provided.

- Description of Operation: Operational limitations/conditions/procedures were not described in enough detail (e.g., lost-link procedures).
- Pilot Experience: Information showing that a pilot could safely operate over people not provided

Further information regarding rejected waivers has been provided (D. Bhadra and M. Lukacs, personal communication, 13 August 2020). From this, waivers are rejected owing to:

- Inadequate CONOPS descriptions
- Inadequate description/demonstration of safety measures
- Inadequate description of area specific information (e.g., population density)

In addition, it was indicated that evaluation of Part 107 waivers to identify future areas of demand has not been completed. Doing so would seemingly be possible given some trends observed with some CONOPS (e.g., linear infrastructure inspection). Importantly, once CONOPS are approved, that approval provides a "template" that others can utilize, resulting in an increase in operations associated with that CONOP.

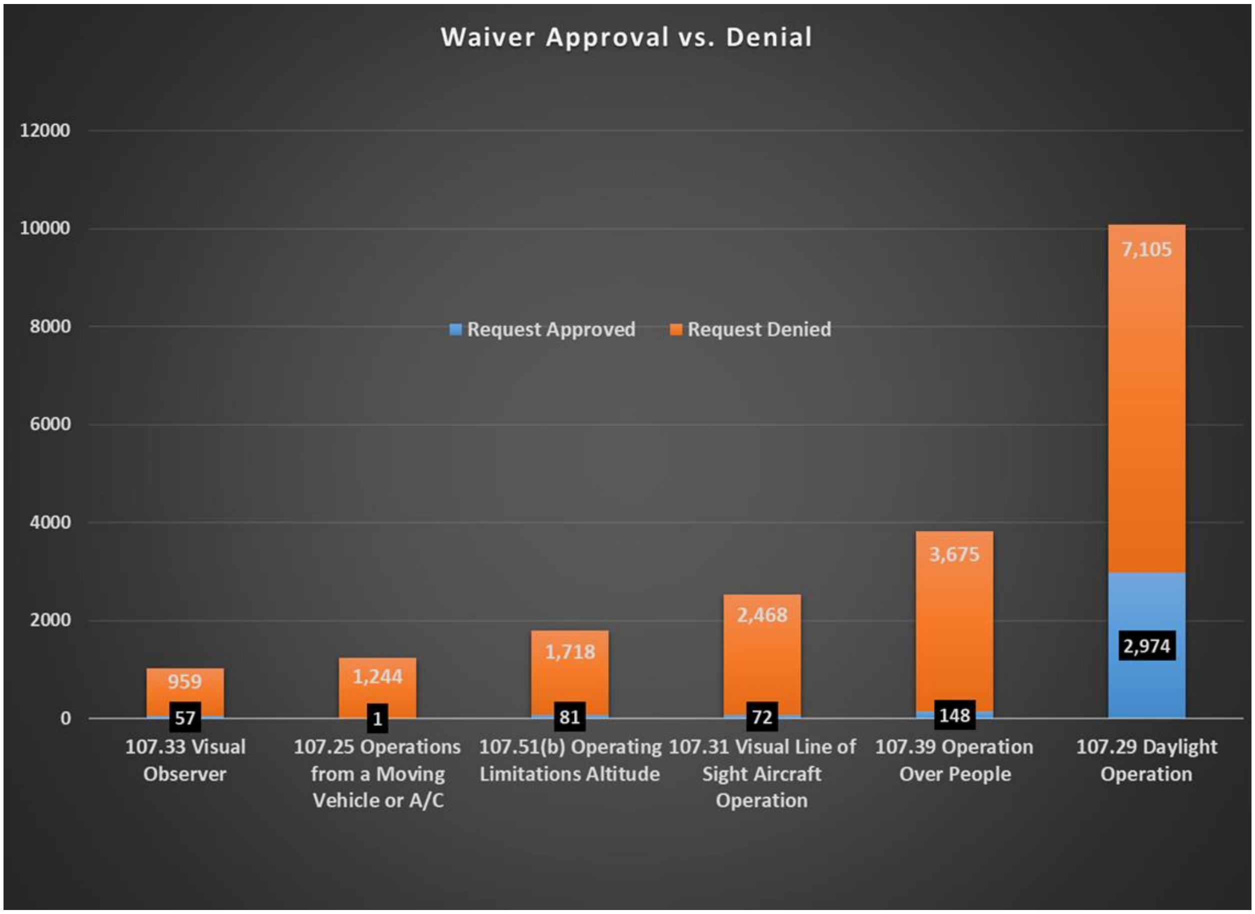


Figure 13. Illustration of proportion of accepted and rejected Part 107 waivers for different waiver categories. From D. Bhadra (personal communication, 19 August 2020).

5.3.2 Analysis of Part 107 Approval Letters

Approved Part 107 waivers provide insight into CONOPS and data associated with CONOPS. As such, the Part 107 waiver analysis involves subtasks 1-2 and 7-8 from the subtask list provided in Section 3.1 of this document.

5.3.2.1 Data

Approved Part 107 waivers were extracted from the FAA Part 107 website on 18 April 2020 (data spans 15 June 2016 to 18 April 2020). These approved waivers are provided as PDF files.

5.3.2.2 Methodology

Approved Part 107 waivers were analyzed using a combined approach of mining the PDF files using code and manual analysis. The manual analysis was required because variations in information provision in the PDF files preclude a complete analysis using software.

Approved Part 107 waivers were analyzed to identify types of mitigations that were utilized and any restrictions on authorized operations. Mitigations are enabling technologies and/or procedures that enable an operation. Restrictions, on the other hand, are requirements that must be followed for the operation to proceed. For instance, a BVLOS operation may be enabled by a DAA system, but operations may be restricted to be below 400 ft. The line between mitigations and restrictions, however, can be blurry, as a restriction can be considered to be a mitigation. Thus, at times in the following, both terms will be used for some items.

The types of Part 107 waivers examined include:
- Part 107.31 – Beyond Visual Line of Sight (BVLOS)
- Part 107.35 – Flying Multiple Small Unmanned Aircraft Systems (sUASs)
- Part 107.39 – Flying Over People
- Part 107.51b – Operating Limitations: Altitude Above 400 ft Above Ground Level (AGL)
- Part 107.51c – Operating Limitations: Minimum Visibility
- Part 107.51d – Operating Limitations: Minimum Distance from Clouds

It is noted that operations at night, which is the most approved Part 107 waiver category (> 4000 waivers), are not analyzed. This type of operation generally follows all Part 107 requirements except for daytime operations and, in doing so, is not considered to be an "advanced" operation like BVLOS or flying over people.

5.3.2.3 Results

5.3.2.3.1 <u>Mitigations</u>

Mitigations were identified initially by considering approved BVLOS waivers. The consistent set of identified mitigations is:
- Visual Observers (VOs)
- DAA technology
- Onboard cameras
- Chase planes
- Tethers

Note, some restrictions listed in the next section may also be considered mitigations.

As shown in Figures 3-814-19, VOs were the primary mitigation technique for all approved Part 107 waivers, and no waivers utilized a chase plane. Notably, for BVLOS waivers (Figure 14), only 4 waivers involved DAA technology, and for 2 of those VOs were also utilized. Undoubtedly, the demand for BVLOS operations is high. These results indicate that establishing proven DAA technology to provide enough mitigation to achieve a desired level of safety is a major barrier to advanced (BVLOS) operations.

Ground-based VOs were the only mitigation method used for approved Part 107.35 and 107.51b operations (Multiple UA and Altitude Above 400 ft; Figures 4 15 and 617). However, for Part 107.35 operations (Multiple UA), one waiver did not list any of these mitigation methods.

Some waivers utilized more than one mitigation method. For example, for approved Part 107.39, 107.51c, and 107.51d operations (Flight Over People, Minimum Visibility, and Minimum Distance from Clouds), some waivers used a combination of ground-based VOs and an onboard camera or a tether (Figures 516, 18, and 819). None of the waivers stated the number of ground-based VOs or the type of DAA technology or onboard camera used for the approved operations.

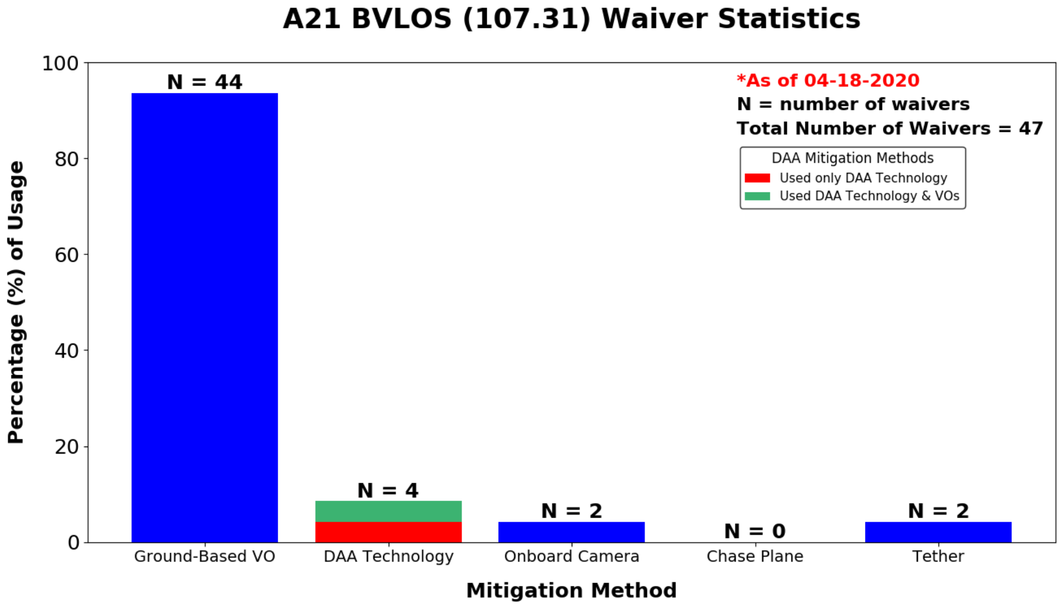


Figure 14. Mitigations utilized in BVLOS (.31) Part 107 waiver.

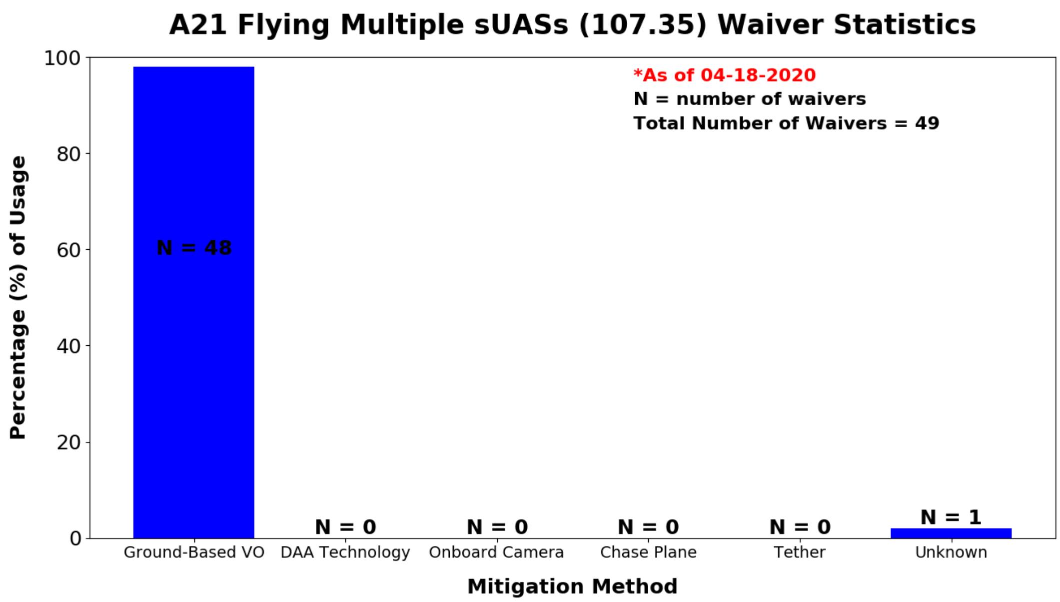


Figure 15. Mitigations utilized in Flying Multiple UA (.35) Part 107 waivers

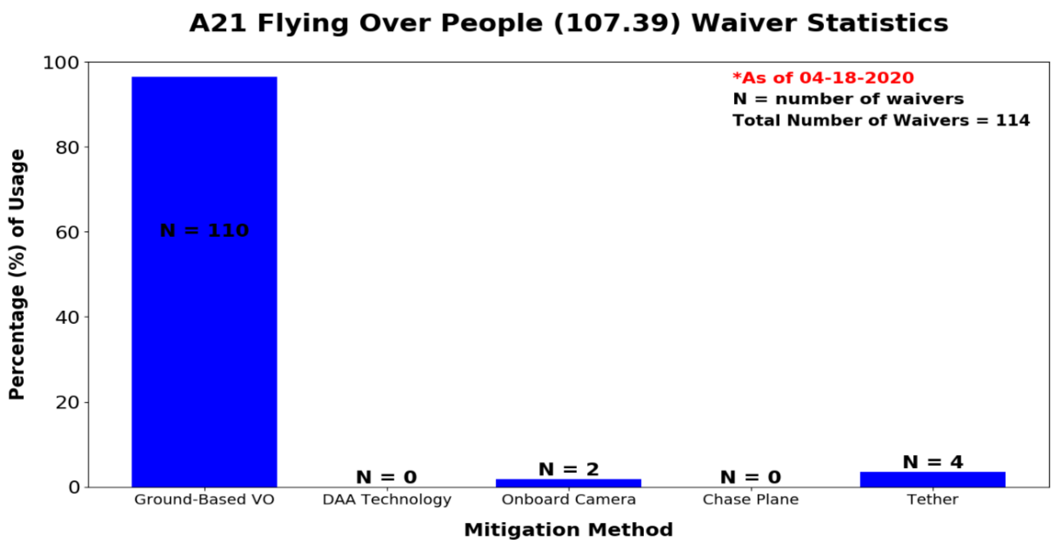


Figure 16. Mitigations utilized in Flight Over People (.39) Part 107 waivers.

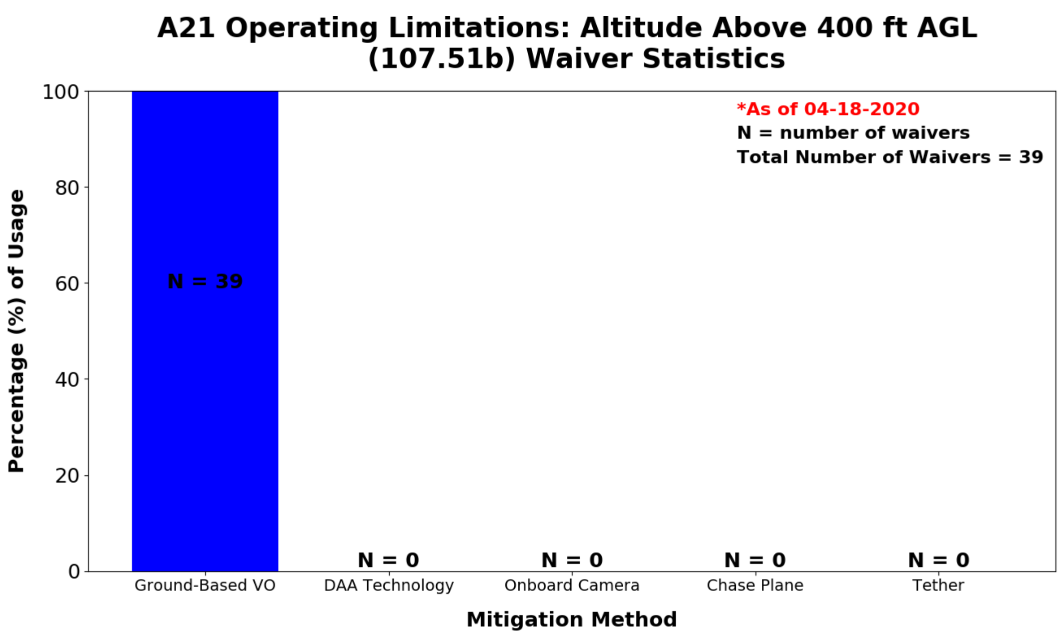


Figure 17. Mitigations utilized in Altitude Above 400 ft (.51b) Part 107 waivers.

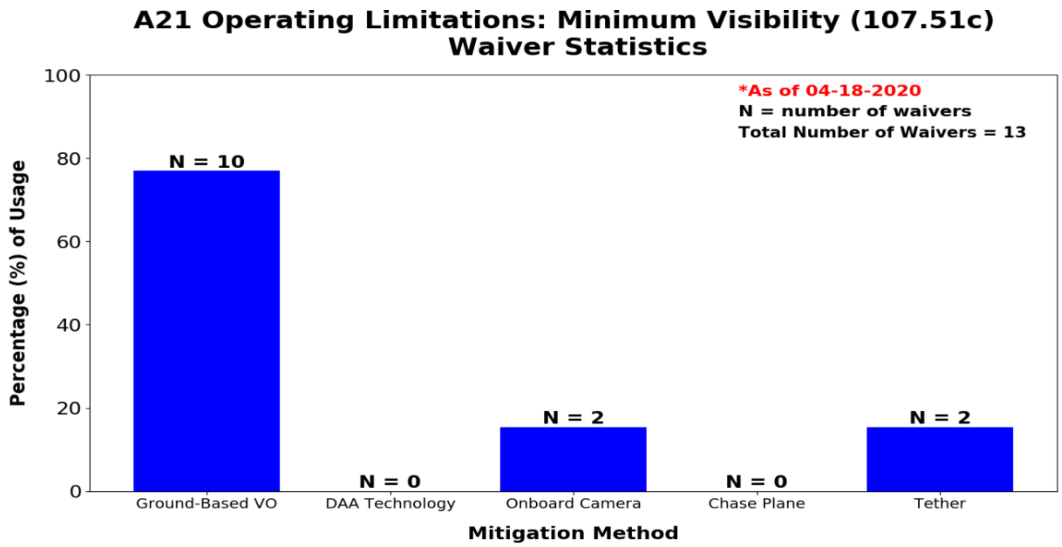


Figure 18. Mitigations utilized in Minimum Visibility (.51c) Part 107 waivers.

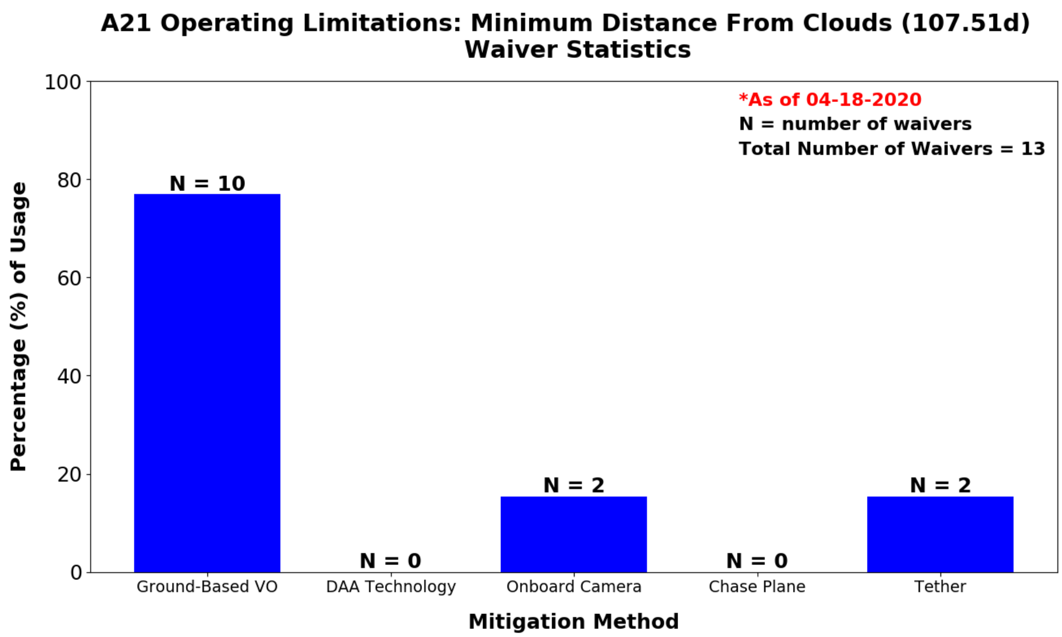


Figure 19. Mitigations utilized in Minimum Distance from Clouds (.51d) Part 107 waivers.

5.3.2.3.2 Restrictions

The types of restrictions vary depending on the type of operations that were requested. Nearly all approved waivers contain multiple restrictions. For Part 107.31 (BVLOS) waivers, operations were commonly restricted by maximum flight altitudes ranging from 100 ft to 400 ft AGL, only operating in Class G airspace, maximum ground speeds ranging from 5 to 50 kts, flying over people (both direct participants and non-participants), and by filing a Notice to Airmen (NOTAM; Figure 20). A couple of Part 107.31 waivers with a restriction for flying over people were also mandated to use a parachute system, but the type of parachute system was not specified. Overall, for Part 107.31 operations, filing a NOTAM was the most common restriction. It is noted that flight over people is, in many ways, an allowance. However, waivers commonly restricted that allowance (e.g., only flight over participants or flight over people if a parachute system is utilized).

Filing a NOTAM was also the most common restriction for Part 107.35 and 107.51b operations (Multiple UA and Altitude Above 400 ft; Figures 10 and 12). However, for operations under Part 107.51b, a couple waivers included a distance limitation (0.5 nm and 1.2 nm) within their NOTAM restriction. Additionally, maximum flight altitudes ranged from 500 ft to 1,700 ft AGL for operations under Part 107.51b waivers (Figure 23), and 100 ft to 400 ft AGL for Part 107.35 waivers. Additional Part 107.35 restrictions include maximum ground speeds ranging from 6 knots to 35 knots, only operating in Class G airspace, and adhering to weight restrictions (which include payload weight) that range from 0.75 to 18.10 lbs. (Figure 21). Lastly, for Part 107.35 operations, the type of sUAS used was not stated in every waiver. However, some waivers specified that the following sUASs were utilized: DJI Flame Wheel, DJI S900, Hummingbird 7000, 3D Robotics Iris+, 3D Robotics X8+, and the 3D Robotics Solo.

For operations under Part 107.39, 107.51c, and Part 107.51d (Over People, Minimum Visibility, Distance from Clouds), height was the primary restriction (Figures 11, 13, and 14). Maximum flight altitudes ranged from 100 ft to 400 ft AGL for Part 107.51c and Part 107.51d operations, and 21 ft to 200 ft AGL for Part 107.39 operations. Operations under Part 107.51c and Part 107.51d involved the same waivers and, therefore, the same restrictions such as maximum ground speeds ranging from 11 to 50 kts, only operating in Class G airspace, and only operating during daylight hours. Additionally, cloud and visibility restrictions were present for operations under Part 107.51c and Part 107.51d. Out of the 13 waivers (as of 18 April 2020), 9 waivers contained cloud-related restrictions such as staying clear of clouds, operating 100 ft below clouds, or operating more than 500 ft below clouds and more than 2,000 ft horizontally from clouds (Figures 13 and 14). Moreover, every waiver contained a visibility restriction. Examples of these include operating in visibilities of less than 3 mi but greater than 2 mi, less than 1 mi, less than 300 ft, less than or equal to 0.5 mi, greater than 0.5 mi but less than or equal to 2 mi, greater than 2 mi, or 3 mi (Figures 13 and 14). Additionally, most Part 107.51c and Part 107.51d waivers did not specify the type of sUAS used. However, a few waivers specified that the Hummingbird 7000 was used for the approved operations.

Operations conducted under Part 107.39 contained restrictions for flying over people, flying over moving vehicles, aircraft weight (which includes payload weight), aircraft make and model, maximum ground speed, maximum wind speed, and flying during the night (Figure 22). Out of 114 waivers, 90 waivers contained a restriction (or, functionally, an allowance) for flying over people. Within this restriction, most of the waivers contained another restriction that stated the sUAS must be equipped with a parachute system in order to fly over people. The primary parachute systems used were the ParaZero SafeAir Mavic and the ParaZero SafeAir Phantom (Figure 22). Additionally, the types of sUAS used for these operations were the DJI Mavic 2 Pro, Mavic 2 Zoom, Mavic 2 Enterprise, and the DJI Phantom 4 (Figure 22). The primary aircraft weight restriction was 2.53 lbs. and very few waivers allowed operations over moving vehicles.

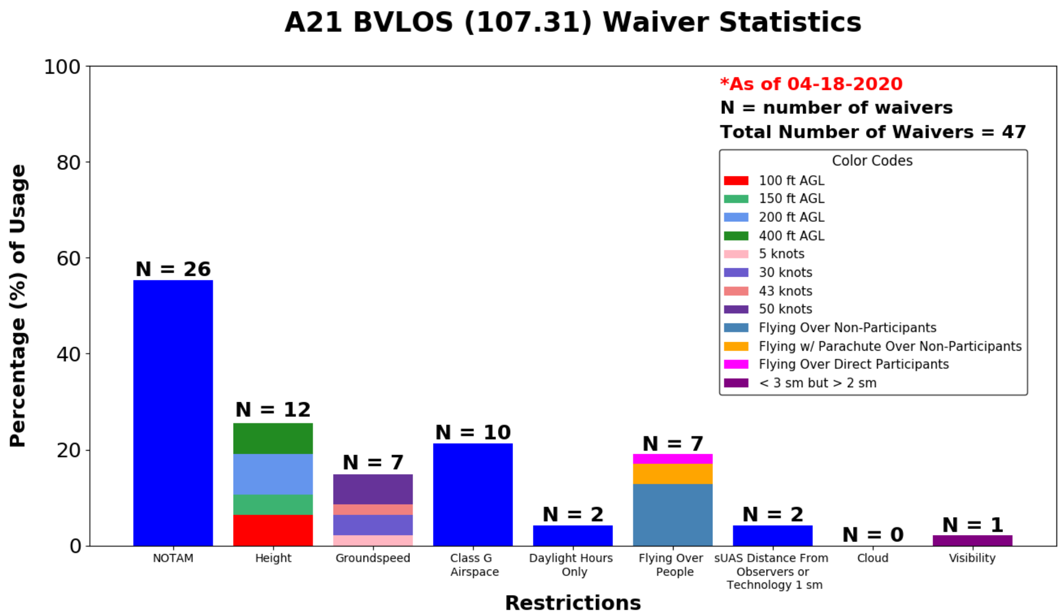


Figure 20. Restrictions associated with BVLOS (.31) Part 107 waivers.

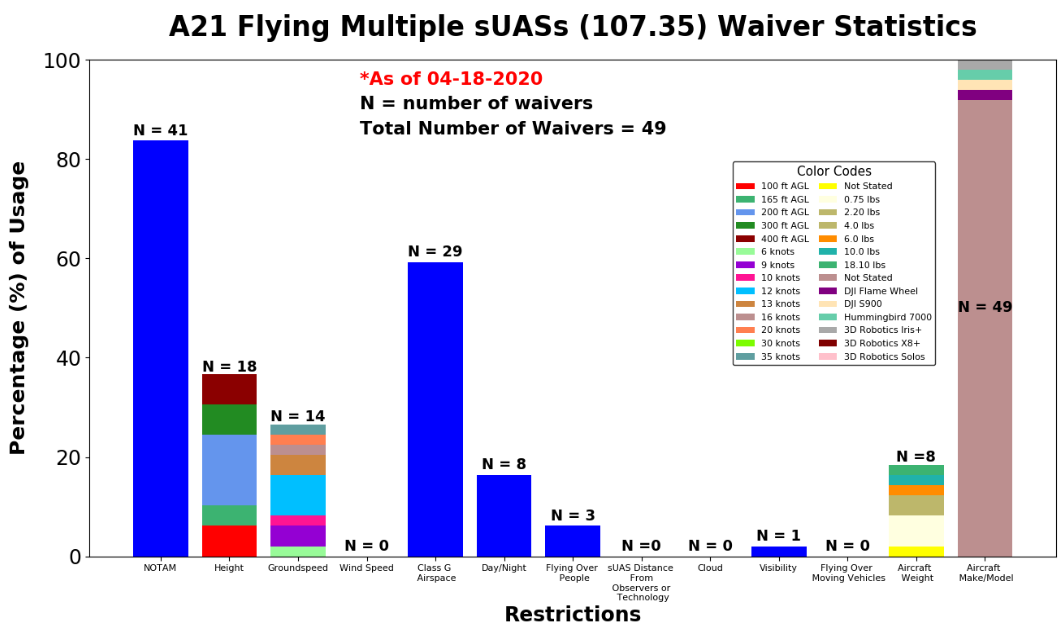


Figure 21. Restrictions associated with Flying Multiple UA (.35) Part 107 waivers.

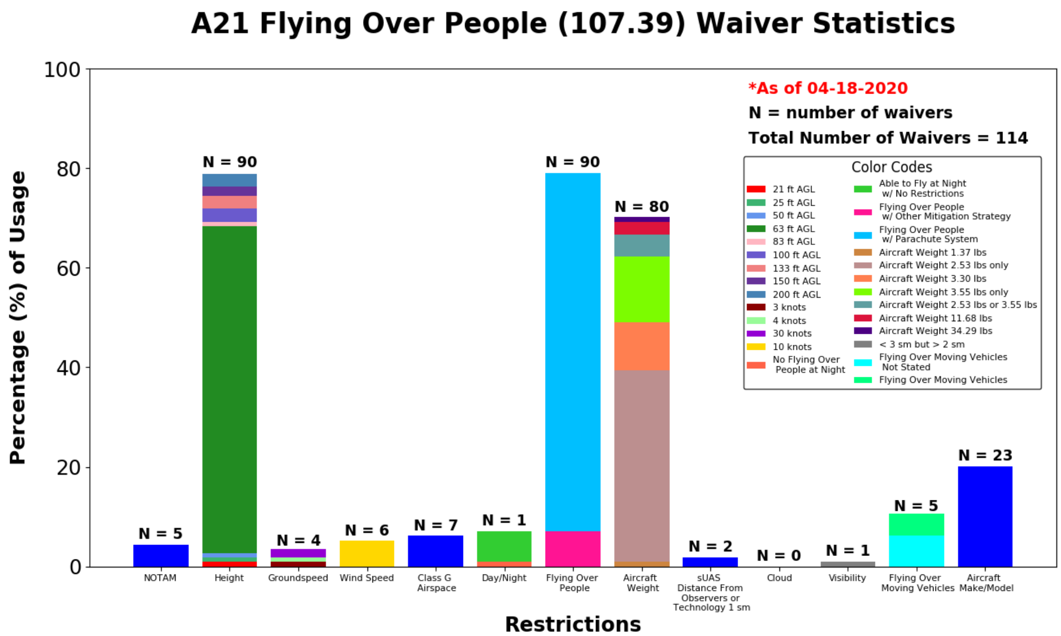


Figure 22. Restrictions associated with Flying Over People (.39) Part 107 waivers.

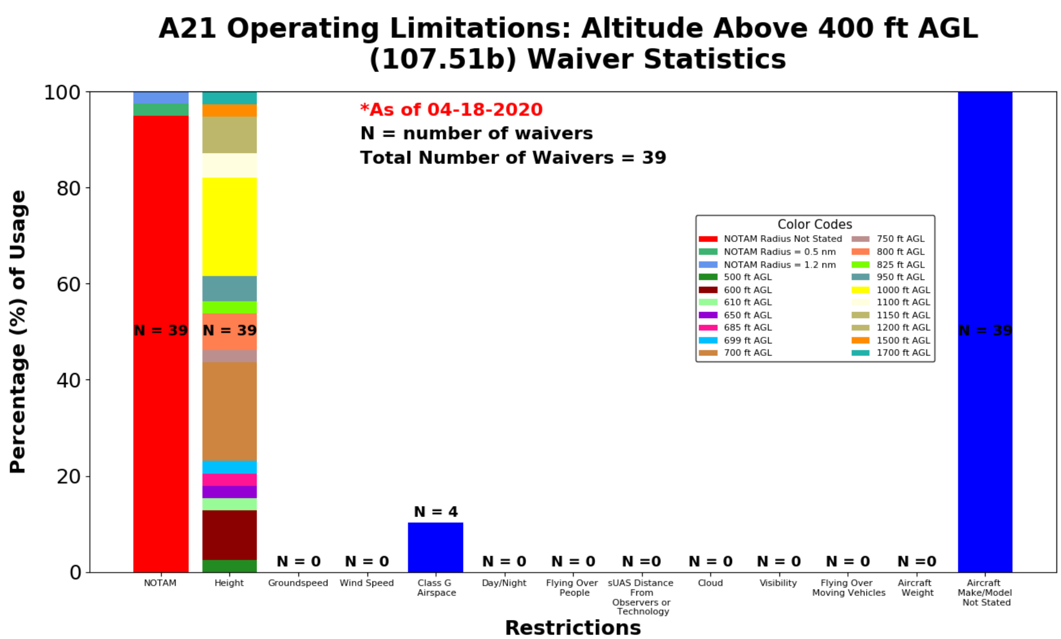


Figure 23. Restrictions associated with Altitude Above 400 ft (.51b) Part 107 waivers.

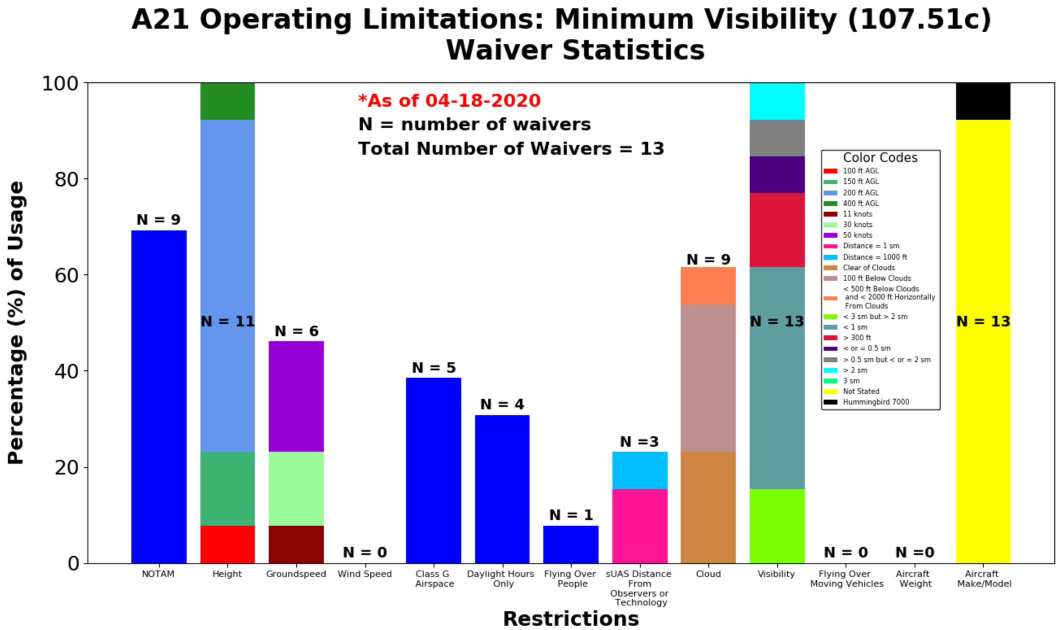


Figure 24. Restrictions associated with Minimum Visibility (.51c) Part 107 waivers.

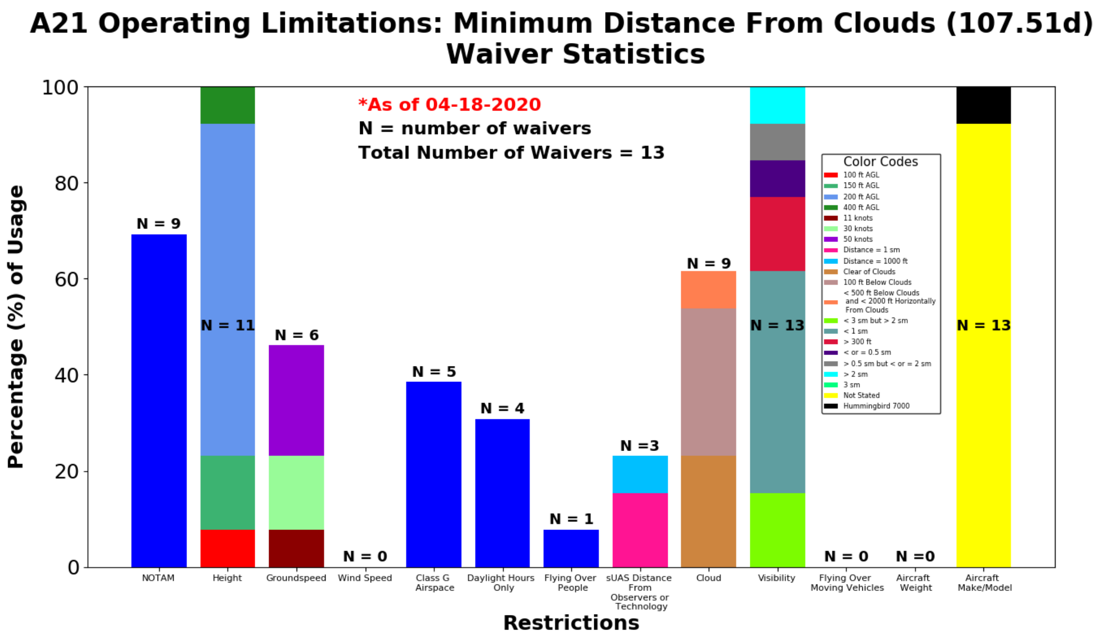


Figure 25. Restrictions associated with Minimum Distance from Clouds (.51d) Part 107 waivers.

5.4 Data Needs

The framework that is used for assessment of UAS waivers is SMS (e.g., U.S. Department of Transportation 2020). Of particular importance to obtaining a waiver is the Safety Risk Management (SRM) component (e.g., U.S. Department of Transportation 2017). Guidance for applying SRM to UAS is provided by U.S. Department of Transportation (2019). This framework establishes a risk-based approach to assessment of UAS waivers.

Within the SMS framework, waivers can be evaluated using different means. What drives this are the inherent differences in performance metrics for different hazard consequences. For instance, the performance metric for a DAA system is completely different from a performance metric used to evaluate ground-collision severity (whether with property or people). Referring back to
Figure 12 expanded and non-segregated operations can be categorized, when considering high-level hazards, in a manner similar to that shown in Table 9. This list is not meant to be exhaustive (many additional missions could be listed, for instance). Moreover, categories are not exclusive—a use case could involve BVLOS and Operations Over People, for instance. It does, however, illustrate critical classes of functionalities that mitigate high-level hazards. For BVLOS, the critical functions are generally considered to be DAA and C2. The degree of C2 performance, however, can be alleviated by utilizing autonomy (e.g., autonomous maneuvers that do not require the pilot to execute an aircraft maneuver). When autonomy is used in this manner, the burden shifts from C2 to software performance, which involves a different set of performance metrics/test data (e.g., Askelson et al. 2017). High-level performance metrics and, thus, the data that are required to receive a waiver, are also listed in Table 9. With these, failure rates are not generally listed unless they play a leading role in realization of the primary hazard (e.g., airworthiness).

The data required to evaluate a CONOPS can be understood by considering results from another ASSURE project: A11L.UAS.50 (Phase I) – UAS Test Data Collection and Analysis Phase I (referred to as A19 Phase I). This effort defines a safety case framework and associated data schema. The safety case framework, which originated with the Virginia Tech Mid-Atlantic Aviation Partnership (MAAP), is illustrated in Figure 26. As illustrated in this figure, a safety case framework can be organized into the following components:

- Operational Context Definition
    - Concept of Operations
    - Risk Assessment
- Data Collection
    - Test Planning
    - Testing and Demonstration
- Safety Case
    - Safety Case Compilation
- FAA Approval

A data schema that defines data associated with each of these components has been developed as part of A19 Phase I. While each component in this framework is critical, the data collection component is underscored, as this component is where the critical data that prove that the desired level of safety is attained are generated. It is noted that development of a successful safety case depends upon definition of appropriate metrics and associated performance levels. This is often a major challenge, as determining what performance level results in an acceptable level of risk relative to the NAS, which is a highly complex system, is very difficult.

Another process for enabling CONOPS is development and utilization of standards. This process greatly lightens the burden for the applicant, as the Operational Context Definition and Test Planning phases are, for the most part, pre-defined. The fundamental challenge of defining performance level requirements and tracing them to overall NAS risk, however, remains.

Table 9. Non-exhaustive list of advanced UAS operations, example missions, primary hazards, critical enabling functionalities, and performance metrics/data.

Operation Category	Example Missions	Primary Hazard	Critical Functions	Performance Metrics/Data
BVLOS	Linear infrastructure inspection Precision agriculture Surveying Package delivery	Collision with aircraft	DAA, C2/Autonomy	Risk ratio, C2 availability and reliability, Software performance
Operations Over People	Package delivery Reporting Law enforcement	Collision with people	Airworthiness, Mitigation of loss of controlled flight	Flight hours, Accidents and incidents, Test data for mitigations (e.g., parachutes)
Operations Over Moving Vehicles	Package delivery Reporting Law enforcement	Collisions involving vehicles (including vehicle accidents induced by aircraft)	Airworthiness, Mitigation of loss of controlled flight	Flight hours, Accidents and incidents, Test data for mitigations (e.g., parachutes)

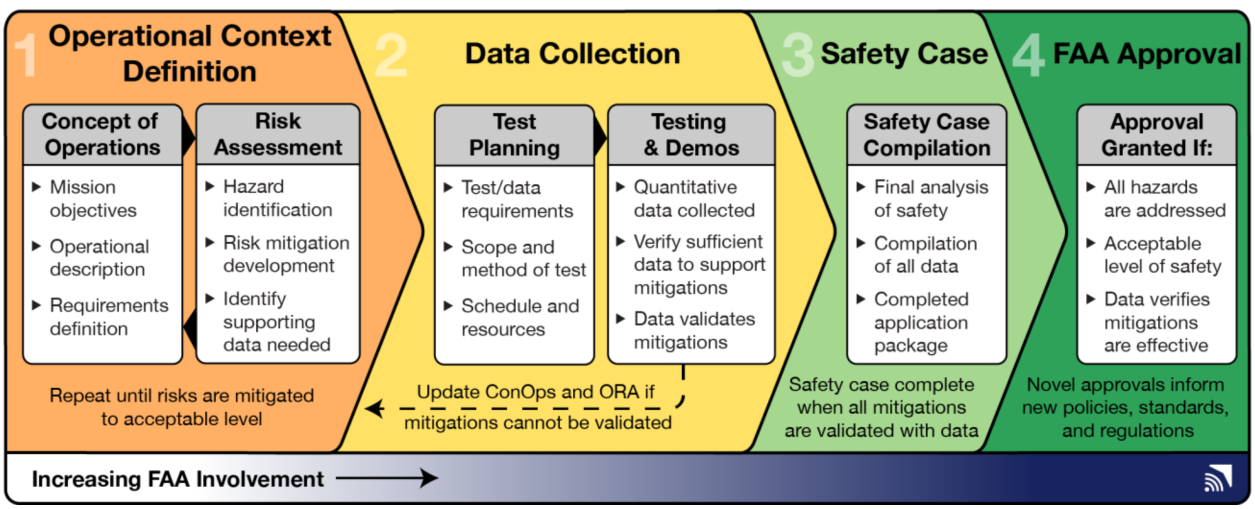


Figure 26. The Virginia Tech MAAP safety case development process.

Given this, numerous data sets that are being collected are very helpful for evaluating CONOPS. The most helpful data sets are summarized in

Table 10.

Table 10. Data sets that enable evaluation of CONOPS.

Data Type	Information	Utilization

MLS	Some CONOPS information, flight operations data, accidents, and incidents	Airworthiness evaluation Evaluation of system and subsystem failures
Safety Cases (Test Sites, IPPs, others)	CONOPS, Test data	Direct CONOPS evaluation
ASIAS for UAS	Flight operations data	Airworthiness evaluation Evaluation of system and subsystem failures
UAS sightings, UAS detection data, registration data, etc.	Varied	Evaluation of NAS risk

The A21 team, of course, does not have access to all data. Consequently, it cannot perform a detailed data gap analysis for categories highlighted herein (e.g., in Table 9). It can, however, highlight fundamental needs, which include:

- Clear definition of the operational context (including system limitations)
- Defined metrics and performance requirements
- Test data that illustrate conformance with performance requirements/expectations within the operational context

These needs have driven the A19 Phase I effort, which is part of a research arc having the end goal of development of a test data collection and analysis system. The purpose of this system is not only to enable applicants to provide more effective safety cases, but to enable analysis of test data across the system to evaluate results, identify areas requiring more research, etc. Such a system could significantly enhance evaluation of CONOPS by improving the quality of individual safety cases and enabling evaluation of systems through data aggregation. Another important effort is the ASSURE research project UAS Parameters, Exceedances, Recording Rates for ASIAS (A20; Aviation Safety Information Analysis and Sharing). This system developed in this effort will provide flight operational data, which will provide invaluable information regarding UAS reliability, failure modes, etc.

5.5 Conclusion

5.5.1 Answers to Research Questions

The research questions that drove this analysis are:

- What are current UAS CONOPS relevant to sUAS expanded operations including operations over people and other waiverable UAS integration activities?
- What performance metrics must be considered toward determining the performance of a UAS CONOP?
- What data are necessary to evaluate actual or predicted performance under the CONOPS?

Question 1. This question can be addressed by leveraging

Table 8, the CONOPS material associated with it, and the additional CONOPS information that follows it. The three primary classes of operations that have been identified based upon high-level hazards are BVLOS, operations over people, and operations over moving vehicles (Table 9). CONOPS that can be executed LOS will be enabled by the ability to operate over people and moving vehicles. Thus, all CONOPS listed in

Table 8 as likely not needing BVLOS capability are relevant to those two expanded operations/capabilities. BVLOS operations, on the other hand, will generally inherently involve some possibility of operations over people and operations over moving vehicles. Thus, these applications and, consequently, all CONOPS listed in

Table 8, are relevant to operations over people and operations over moving vehicles.

Table 8 provides an indication of CONOPS that are most relevant for BVLOS operations. All CONOPS labelled as 'Yes' and 'Situationally Dependent' are deemed to be relevant for BVLOS operations. These are:

- Aerial Data Collection
- Aerial Surveying/Mapping
- Agriculture
- Emergency Services
- Flight Training/Education
- Inspection
- Multiple Applications
- Research
- Search/Rescue
- Surveillance, Monitoring, etc.
- Other UAS Applications

CONOPS labelled with 'Likely No' are:

- Aerial Photography/Videography
- Marketing

Even for the 'Likely No' CONOPS, however, one can construct scenarios where BVLOS would be enabling. Thus, BVLOS capability would be enabling for all CONOPS, but is deemed to be much less needed for Aerial Photography/Videography and Marketing.

Question 2. The answer to this question is provided in Table 9.

Question 3. The answer to this question is provided in Table 9.

5.5.2 Summary

To understand UAS CONOPS, the team leveraged results from other ASSURE efforts (A2 and 18) and classifications developed by others [e.g., Strande (2019)]. The A2 and A18 results provide tremendous detail regarding a variety of CONOPS. A very high-level means of summarizing CONOPS, according to high-level hazards, is:

- BVLOS
- Operations Over People
- Operations Over Moving Vehicles

This breakdown could further be simplified according to air risk and ground risk. Each of these categories contains many CONOPS. Moreover, CONOPS often will involve more than one of these categories.

To evaluate data requirements for CONOP evaluation both rejected and approved Part 107 waivers were analyzed. Information regarding rejected Part 107 waivers was obtained from published results and correspondence with FAA sponsors. Part 107 approval letters were extracted from the FAA Part 107 website.

The vast majority of Part 107 waiver requests are rejected. In the simplest sense, these rejections occur because the associated safety cases are insufficient. As shown by FAA (2020c), for BVLOS and operational over people waiver requests the following deficiencies were identified:

- BVLOS
  - Command and Control (C2): Lacking operational data (e.g., operating range) and/or Federal Communications Commission (FCC) approval
  - DAA: Lack of information regarding methods or procedures and performance for DAA
  - Operational Limitations: Lack of information regarding how environmental hazards would be mitigated
  - Crew: Lack of information regarding crew qualifications (who has what training) and how the training of the crew is assured
- Operations Over People
  - Ground Collision Severity: Test data that were not for the sUAS to be used were provided or calculations (estimates) were provided instead of test data.
  - Laceration Injuries: Test data that were not for the sUAS to be used were provided or statements indicating propeller guards would be used without supporting test data as their efficacy or no information provided.
  - Description of Operation: Operational limitations/conditions/procedures were not described in enough detail (e.g., lost-link procedures).
  - Pilot Experience: Information showing that a pilot could safely operate over people not provided

Another way of summarizing why Part 107 waivers are rejected is (D. Bhadra and M. Lukacs, personal communication, 13 August 2020):

- Inadequate CONOPS descriptions
- Inadequate description/demonstration of safety measures
- Inadequate description of area specific information (e.g., population density)

Analysis of approved Part 107 waivers identified the following set of mitigations:

- Visual Observers (VOs)
- DAA technology
- Onboard cameras
- Chase planes
- Tethers

Very few waivers utilized DAA systems, while VOs were heavily used. This illustrated the barrier that acceptable DAA technologies pose to enabling BVLOS operations. Restrictions include flight altitude, aircraft type, aircraft weight, airspace class, ground speed, not flying over people, not flying over moving vehicles, daytime-only operations, visibility, distance from clouds, filing a Notice to Airmen (NOTAM), and utilization of a parachute. These restrictions can also be considered mitigations. Utilization of a parachute was a common mitigation/restriction for operations over people waivers, which illustrates the progress that has been realized with this type of mitigation.

SMS is the framework that is utilized to evaluate waivers. However, within that framework, different metrics and performance requirements are used according to the mitigation being evaluated (e.g., risk ratio for DAA for BVLOS, parachute performance for Operation Over People, etc.). A key to successful enablement of UAS operations is agreement upon the metric being used for evaluation and associated performance requirements.

Data sets that support UAS CONOPS evaluation are discussed. Fundamental data needs include:

- Clear definition of the operational context (including system limitations)
- Defined metrics and performance requirements
- Test data that illustrate conformance with performance requirements/expectations within the operational context
-

Two ASSURE efforts, A19 and A20, are developing systems for collection of both test and operational data. These efforts are expected to enhance not only collection of data regarding UAS CONOPS, but also evaluation of progress regarding CONOPS (including aggregated data) and needs for further research. It is expected, then, that the efforts herein and in related efforts will accelerate realization of UAS CONOPS.

6 Addendum 3: Technical Report – Data Analysis

6.1 Introduction

This research task focuses on analyzing existing UAS data to inform parallel A21 research tasks and to inform the FAA regarding the information contained in and that can be derived from the data. This task includes the following sub-tasks:

- Characterization of available data including a quantitative analysis of the data sets and identification of relational correlations across data sets
- Analysis of waiver requests and the current NPRMSNPRMs to characterize data needs of associated SMS processes
- Identify current data trends, including geographic activity and impact of current or past FAA programs (if known)
- Identify additional types of data that are needed and improvements to current data practices including data standardization and collection methods, and quantifying current limitations of sparse data sets

Research Questions/Goals

- What are the quantitative characteristics of the data set? (i.e., number of records, sparsity of data, etc.?)
- What is the set of most informative quantitative analyses of current activities both within and across different data sets that can be provided, including trend analyses? (and complete such analyses)
- What trends exist with Part 107 waiver activity and NPRM regulatory language?
- What SMS processes govern the analysis of waiver applications, and the data requirements to validate each?

6.2 Data Set Analysis

This task characterizes the currently available data and provides quantitative indications of current activities both within and across different data sets. This includes an assessment of the type and quality of the data and identification of relational connections between data and across all data sets. To avoid duplication of effort with similar work in Tasks 1-1 and 1-2, only select subset of the data sets and variables are described in Section 6.2.1.

6.2.1 Quantitative Data

In this project, data were collected from the FAA's available and sharable UAS data, including the following areas:

- UAS registrations for Section 336 (hobbyists) and Part 107 (commercial)
- Remote Pilot in Command (RPIC) Registration Databases
- Notices of Proposed Rulemaking (NPRM)
- UAS Facility Maps (UASFM)
- Certificate of Authorizations (COA) Application Processing System (CAPS)
- Remote pilot certificates
- Part 107 exams and exam results
- Mission Logging System (MLS) operations and incidents
- Waiver Acceptance Letters
- Reported UAS Sighting Incidents
- Other applicable COE ASSURE research projects.

Table 11 presents primary variables from each data set that were used in the quantitative analysis, along with the variable description, type, and scale. The data was received directly from the project's FAA sponsors or the FAA's Freedom of Information Act (FOIA) Electronic Reading Room[4].

Table 11. Variables, description, and scale for quantitative analysis.

Variables	**Description**	**Type/Scale**
Full UAS Registration Part 107 Commercial		
Registration_Number	Registration number	String/Nominal
Registration_Date_UTC	Registration state and time	Date-Time/Nominal
Manufacturer	Manufacturer name	String/Nominal
Model	UAS Model	String/Nominal
Serial_Number	UAS Serial Number	String/Nominal
Country_Name	Country of the registration	String/Nominal
Postal Code	Zip code	String/Nominal
Status	Registration status: Active, Inactive	String/Nominal
Full UAS Registration Section 336 Hobbyists		
Registration_Number	Registration number	String/Nominal
Status	Registration status: Active, Inactive	String/Nominal
Postal Code	Zip code	String/Nominal
Country_Name	Country	String/Nominal
Registration_Date_UTC	Registration date and time	String/Nominal
UAS Registrations City Stat County Count data set (by quarter)		
Country	Country of the registration	String/Nominal
State/Province/Region	State of the registration	String/Nominal
City	City of the registration	String/Nominal
Postal Code	Zip code	String/Nominal
Registration count	Number of registrations by zip code	Numeric/Ratio
UAS Certification		
US Zip 5	Zip code	String/Nominal
City	City	String/Nominal
State	State	String/Nominal
Country Code	Country	String/Nominal
Number of Records	Number of certificates by zip code	Numeric/Ratio
Aviator	Type of certificate: Part 61 + Remote Pilot or Remote pilot only	String/Nominal

[4] https://www.faa.gov/foia/electronic_reading_room/

Month of RPDOI	Quarter	Month/Nominal
Number	Number of certificates by quarter	Numeric/Ratio
Part 107 Waiver Data		
ID	Waiver application identification number	String/Nominal
Effective From	Waiver date of issue	Date/Nominal
Effective To	Waiver date of expiration	Date/Nominal
Reg	Part 107 regulation numbers	String/Nominal
IPP	IPP or non-IPP waiver	String/Nominal
Issuee	Requesting organization	String/Nominal
Responsible	Applicant name	String/Nominal
Address	Organization address	String/Nominal
ZipCode	Zip code	String/Nominal
Operations Permitted	Types of UAS operations	String/Nominal
Waived	Waived UAS regulations	String/Nominal
MLS operations data (Note: To avoid duplication with Table 6, only variables used in the Task 1-3 analysis are listed here)		
FlightID	Flight identification number	String/Nominal
FlightName	Flight name	String/Nominal
FlightType	Flight type, Public vs Civil	String/Nominal
FK_COA	COA number	String/Nominal
FK_COAMission	COA Mission type	String/Nominal
Start Time	Flight start date and time	Date-Time/Nominal
End Time	Flight end date and time	Date-Time /Nominal
FlightTimeMin	Flight time in minutes	Numeric/Ratio
Flight Hours	Flight time in hours	Numeric/Ratio
Aircraft	UAS type	String/Nominal
AircraftWeight	UAS weight	String/Nominal
OpAltitudeAGL	Operating altitude above ground level	Numeric/Ratio
County	Country	String/Nominal
State	State	String/Nominal
VLosBVLos	Line of sign category (Los, EVLoS, BLoS)	String/Nominal
MLS incident-accidents data (Note: To avoid duplication with Table 7, only variables used in the Task 1-3 analysis are listed here)		
EventID	Event identification number	String/Nominal

FK_COAFlight	COA flight number	String/Nominal
FK_COAFlightAircraft	COA aircraft type	String/Nominal
Event Type	Type of incidents/accidents	String/Nominal
Event Magnitude	Severity of the incidents/accidents	String/Nominal
Start time	Events start date and time	Date-Time /Nominal
End time	Events start date and time	Date-Time /Nominal
Aircraft Lat	Latitude of the UAS	Numeric/Ratio
Aircraft Lon	Longitude of the UAS	Numeric/Ratio
Flight Phase	Phase of flight	String/Nominal
Airspace Class at time of Event	Airspace class at the time of event	String/Nominal
UAS incident sighting analysis		
Date of Sighting	Date and time of sighting reports	String/Nominal
State	State of sighting reports	String/Nominal
City	City of sighting reports	String/Nominal
Summary	Detailed narrative	Text/Nominal

6.2.2 Qualitative Data

This project utilized the available qualitative data sources for UAS, including Waiver Safety Explanation Guidelines (WAG) for Part 107 Waiver Applications, NPRMs database, FAA Safety Management System, FAA Unmanned Aircraft Systems Safety Risk Management Policy, and Federal Aviation Administration Safety Risk Management Guidance: The 5 Step Process (AVP-300-003-JA1). The following documents were used in this study:

- Trend Analysis Beyond Visual Line of Sight (107.31) Waiver
- Trend Analysis OOP Operations Over People (107.39(a)) Waiver
- Trend Analysis Night Operations (107.29) Waiver
- FAA-2018-1084-0001- 7 CFR Part 1774- Special Evaluation Assistance for Rural Communities and Households Program (SEARCH)
- FAA-2018-1086-0001- 14 CFR Part 107- Safe and Secure Operations of Small Unmanned Aircraft Systems
- FAA-2018-1087-0001- 14 CFR Part 107- Operation of Small Unmanned Aircraft Systems Over People
- FAA-2019-0364-0001- 14 CFR Part 107 - Exception for Limited Recreational Operations of Unmanned Aircraft
- FAA-2019-1100-0001- 14 CFR Parts 1, 47, 48, 89, 91, and 107- Remote Identification of Unmanned Aircraft Systems

6.3 Data Preparation, Integration, and Aggregation

This task involved data preparation including data cleaning, transforming, and merging for quantitative analysis. Quantitative data were mainly used for UAS registrations, remote pilot certificates, Part 107 exams and results, waiver requests, MLS operations and incidents, and UAS sighting incidents. Microsoft™

Excel™ was used for data exploration and preparation. To ensure the data usability, the data sets were scrutinized to identify unusable or irrelevant data (e.g., consider sighting report data, a sighting report with data missing from too many attributes provide little value to analysis or model preparation; and non-relevant data such as reports that describe events other than the sUAS sighting). These unusable and unrelated data were not included in the quantitative analysis.

Additionally, within this research task, improvements upon data collection and standardization are proposed. Additional data elements are identified that provide a complete picture of UAS operations. Inconsistencies are identified in data collected by different sources and recommendations for data standardization are made. This effort also examined the correlations or consistencies in the results provided by different data sets in order to better understand both the data collection methods and potential implications regarding differences across the National Airspace System. In cases where the data are sparse, this was noted as a caveat regarding the generalization of the results deriving from those data.

The following are the notes pertaining to the quality and usability of data, required treatment, and limitations for each data set.

6.3.1 UAS registration data

- Full registration data set for section 336 (hobbyists) covers registration numbers from December 2015 to September 2020. It is limited to the registration number, date, zip code, and country.
- In this data set, dates and times are merged into one field, which presented difficulties for analysis. Accordingly, data splitting was conducted to separate the merged date and time data.
- Date variable does not have a standardized format, resulting in errors in analysis. To correct the issue, reformatting this variable was implemented.
- Full registration data set for Part 107 (commercial use) faces all the same challenges, as for Part 336 (hobbyist) mentioned above.
- Part 107 registration data set includes more variables, such as the manufacturer and model of UAS. However, the data for these variables contains inconsistent manually entered text fields, rather than standardized selections, which leads to inconsistent data for UAS models and manufacturers. Excessive manual data standardization prior to analysis is currently necessary to yield usable data. We suggest using checkboxes or radio button in the data collection form to avoid this problem in the future.

6.3.2 Remote pilot certificate and Part 107 exam data

- Certificate data are only available by quarter, which limits the trend analysis to quarterly trend only.
- The data do not differentiate initial certification from re-certification; therefore, there is a possibility that these data only include the number of initial certificates, not the total number of certificates actually issued. Accordingly, the results should be interpreted with this note in mind.
- The number of certificates is only available for two types of certificates, Part 61 + Remote Pilot or Remote pilot only.
- Part 107 exam data is reported as discrete daily data.

6.3.3 Waiver application data

- Waiver application data are available only as textual data from the FAA FOIA library in PDF format. There is no information regarding approved and denied requests. This information was provided by the FAA through several charts rather than actual discrete or aggregate data.

- In order to analyze the data, those PDF documents were extracted from the website and then converted and consolidated into a Microsoft™ Excel™ file.
- Several waiver applications cover multiple regulations. Current data format prohibits capture of data for multiple regulations in one application. Excessive manual data cleaning is required to capture this information. We suggest using checkboxes to capture multiple regulations as different variables to avoid this problem in the future. The format of data captured from multi-waiver applications were also inconsistent.
- Address fields should be standardized and broken into individual elements to aid geospatial analysis such as mapping results to specific locality. The current format significant data cleaning.

6.3.4 MLS operation and incident data

- The full description of variables in those data sets is included in Table 6 and Table 7. Accordingly, in this task, only selected variables used for analysis are presented to avoid duplication.
- The data set only includes UAS operations and incidents/accidents at selected test sites, so the analysis results can only be generalized to those specific sites.
- Dates and times are merged into the same cell, which prohibits quantitative analysis. Those cells were split in order to separate date and time data attributes.
- Aircraft type field is unstructured, and one certain type is written in several different forms, which makes it challenging to group the operations by aircraft type. Excessive manual data cleaning will be required to make the data usable. We suggest using checkboxes or radio buttons in the data collection form to avoid this problem in the future.
- There are many missing values for important variables, such as aircraft type, start and end times, latitude and longitude, and line of sight category.
- There is a total of 16,770 operations. However, only 55 incidents or accidents were reported from May 2015 to June 2019. The researchers are unsure if the data set accurately reflects the complete set of incidents. The results should be interpreted with this caveat in mind.

6.3.5 Sighting report data

- Dates and times are merged into the same field. Hence, dates were separated from times to allow quantitative analysis.
- To analyze the incidents by the time of day, it requires re-coding the time variable. We assumed that all reported times are in the time zone where the event took place.
- Narratives are not collected in a uniform way, so it is not possible to split the text into different fields, which make narratives not meaningful in quantitative analysis. Some parts that seem consistent in the narrative are incident number, type of hazard, date and time, and aircraft. These fields were extracted from narratives. However, there are excessive missing data in those fields, which makes them unusable.
- Due to the unstandardized data collection form, variables in the data are very unstructured with multiple codes, which make them unusable. Excessive manual data cleaning will be required to make the data usable. We suggest using multiple-choice scales instead of text boxes in the form to avoid this problem in the future.

6.4 Quantitative Analysis and Data Trends to Date

This task consists of the following subtasks:

- Identify variables for the trend analysis reflecting the impact of services and programs such as UAS registrations, certificates, waivers, UAS traffic, and UAS incidents.
- Analyze the data trends to date appropriate statistical analyses.
- Present and interpret the results of trend analysis with proper statistical outcomes including model fit, significance level, and prediction accuracy.

6.4.1 UAS Registrations and Certificates

6.4.1.1 UAS Registration and Certification Introduction

The FAA defines sUAS as "a small unmanned aircraft, weighing less than 55 pounds, and equipment necessary for the safe and efficient operation of that aircraft" (FAA, 2016, p. 42065). sUAS can be used either for recreational or commercial purposes. The demand for sUAS has grown rapidly. As of September 15, 2020, there was a total of 1,701,460 registered UAS; among them 492,448 were commercial registrations, and 1,205,518 were recreational registrations (FAA UAS by Number https://www.faa.gov/uas/resources/by_the_numbers/). In June 2016, the FAA issued the new Small UAS Rule (Part 107), which requires sUAS to be registered and sUAS pilots to have the remote pilot airman certificate and pass the FAA-approved test if the sUAS is used for business or work. If used for recreational purposes, the sUAS over 0.55lbs must be registered, but the operator does not need any permission from the FAA to fly (FAA, 2016). Table 12 summarizes the requirements for various UAS options (FAA, 2017)

Table 12. UAS Options and Requirements.

	Aircraft Requirements*	Pilot Requirements	Airspace Requirements	Types of Operation
Part 107	UAS < 55 lbs.	Part 107 remote pilot certificate with small UAS rating	Airspace waiver or authorization for Class B, C, D, E airspace	VLOS, daytime, Class G, 400 ft., not over people OR waiver provisions
Section 333	As specified in exemption	Part 61 airman certificate	Blanket Certificate of Authorizations (COA) or Standard COA for specific airspace	UAS > 55 lbs.
Experimental Aircraft	Experimental Special Airworthiness Certificate	Part 61 airman certificate	Standard COA for specific airspace	Research and development, crew training, and market survey
Type Certificated Aircraft	Restricted type or special class certification	Part 61 airman certificate	Part 91 airspace requirements	Specified in operating authorization
Public Aircraft	Self-certification by a public agency	Self-certification by a public agency	Blanket COA or Standard COA for specific airspace	Public Aircraft Operations (AC 00-1.1A); UAS Test Site operations
Part 101 Model Aircraft	UAS < 55 lbs.	Community-based organization (CBO) standards	Notification requirement within 5 miles of an airport	Hobby or recreational, VLOS, Part 101 operating rules, CBO standards

*Note: All UAS greater than 0.55 pounds must be registered

In addition, the FAA also issued several NPRMs and Advanced Notice of Public Rulemakings (NPRMs) to describe rules and requirements for the operations of sUAS. Currently, there are five rulemakings that cover different aspects of UAS operations. Table 13 presents those rulemakings titles and publication dates.

Table 13. Recently Published Rulemaking Documents for UAS.

Document name	NPRM Title	Federal Register Publication Date
FAA 2019 1100	Remote Identification of Unmanned Aircraft Systems	December 31, 2019
FAA 2019 0364	Exception for Limited Recreational Operations of Unmanned Aircraft	May 17, 2019
FAA 2018 1084	External Marking Requirement for Small Unmanned Aircraft	February 13, 2019
FAA 2018 1087	Operation of Small Unmanned Aircraft Systems over People	February 13, 2019
FAA 2018 2086	Safe and Secure Operations of Small Unmanned Aircraft Systems	February 13, 2019

Source: https://www.faa.gov/regulations_policies/rulemaking/recently_published/

6.4.1.2 Data Analysis Methods

In order to analyze the trends of UAS registrations in the U.S. over time, descriptive statistical analysis and visualization were used. More specifically, the Microsoft™ Excel™ Pivot table was used to calculate the total number of UAS registrations by type (Section 336 – Hobbyists, and Part 107 – Commercial) and by month. The results were presented in bar charts to show the change of registrations over time for each type, which would provide insight into the pattern of the UAS registration in the U.S. The data were also broken down by locations in heat maps to identify the states and locations with the highest registrations based on the frequency analysis. The heat maps were used for comparison across states and locations regarding registration numbers.

To examine whether the publications of NPRMs have any relationship with the registration trends, the dates, and titles of NPRMs are included in the bar chart. Note that this analysis would not provide any conclusion on whether an NPRM causes an increase or decrease of UAS registrations since there are confounding factors that should be considered and controlled. This analysis is mainly to show whether the publications of NPRMs may have any relationship with the changes in UAS registrations. Additionally, since there is a lag between the NPRM publication dates and the actual implementation of those rules, it is possible that immediate effects are not visible. It is important to note that effects may vary by rulemaking type. For example, interim final rules may have sooner effects than APRMs and NPRMs. Therefore, the dates for other important decisions and announcements are added to the charts, including the announcement of UAS registration rule, operation, and certification requirements for sUAS, Low Altitude Authorization and Notification Capability (LAANC), and UAS Integration Pilot Program (IPP) announcement. Finally, the analysis was conducted only for the UAS registrations in the United States, so information about UAS registrations in other countries was not considered in this project.

Similarly, descriptive statistical analysis and visualization were constructed to examine the trend of UAS remote pilot certification and Part 107 exams. Since the certification data is only available by quarters, the visualizations present only quarterly data. Along with the number of certificates over time, the Part 107 exams and exam results were also examined through descriptive statistics and visualization. Interestingly, the exam data is available by month, which is inconsistent with the certification data. However, in order to ensure the consistency in the trend analysis and the comparison of those trends for this part, the visualization is presented as quarterly data.

6.4.1.3 UAS Registrations Data Analysis Results

The first graph (see

Figure 27) presents the bar chart for section 336 (hobbyists) registrations in the US from December 2015 to November 2019. The results show a very high number of registrations in late 2015 and early 2016, which could be explained by the implementation of the UAS registration rule on December 21, 2015. Then it experienced a sharp decrease in March 2016. This decrease could be explained by a possibility that all registrations from the beginning of the registration process were aggregated and reported in December 2015 and January 2016, high increased the number of registrations in late 2015 and early 2015. The chart shows an increase in registrations from the fourth quarter of 2015 to the first quarter of 2016. However, registrations appear to be in the low end of about 10,000 registrations a month between 2017 to 2019, except for a sharp rise in December 2017, right after the introduction of LAANC in November 2017, which provides near real-time processing of airspace authorization requests for drone operators. Interestingly, the downward trend occurred during the NRPM, which is intended to gather information from the public to help inform the FAA's efforts to assess options for reducing risks to public safety and national security associated with further integration of UAS into the NAS. It is worth noting that the NPRM dates mainly reflect the initiation of the rulemakings not their actual effects since there is a lag between the initiation and the implementation. That could explain the increase in Section 336 registrations to about 20,000 registrations in May 2020.

For Part 107 (commercial) registrations, as shown in

Figure 28, the results indicate a much higher fluctuation in the registration counts. While the average number of registrations per month for Part 107 is relatively lower than for section 336, the registrations changed from month to month between 2016 and 2017. It appears there was an increase in September 2016, followed by a decrease in next several months. This trend could be explained by the announcement of the Operation and Certifications of sUAS requirements on June 28, 2016, which required UAS pilots to get certified. Then the number of registrations increased again in February and March 2017 to more than 6,000 registrations per month, before it decreased slightly in the remaining of 2017. The figure showed a big jump in December 2017 and stayed very high of about 14,000 registrations per month until August 2018. This substantial increase in Part 107 registrations could be explained by the announcement of IPP on November 2, 2017, which enhances the safe drone integration, and the availability of LAANC on November 17, 2017, which provides near real-time processing of airspace authorization requests for drone operators. Then, the number of registrations decreased slightly in October 2018 and then increased again in December 2018. It appears that registrations reached the highest of approximately 14,000 registrations per month for several months before they began to decrease in June 2019. Due to the lag in the effects of NPRMs, as mentioned above, this increase is mainly due to the implementation of IPP and LAANC. Finally, an increase in Part 107 registrations can be observed in May 2020, which could be explained by the implementation of NPRMs, which were published in February, March, and December 2019.

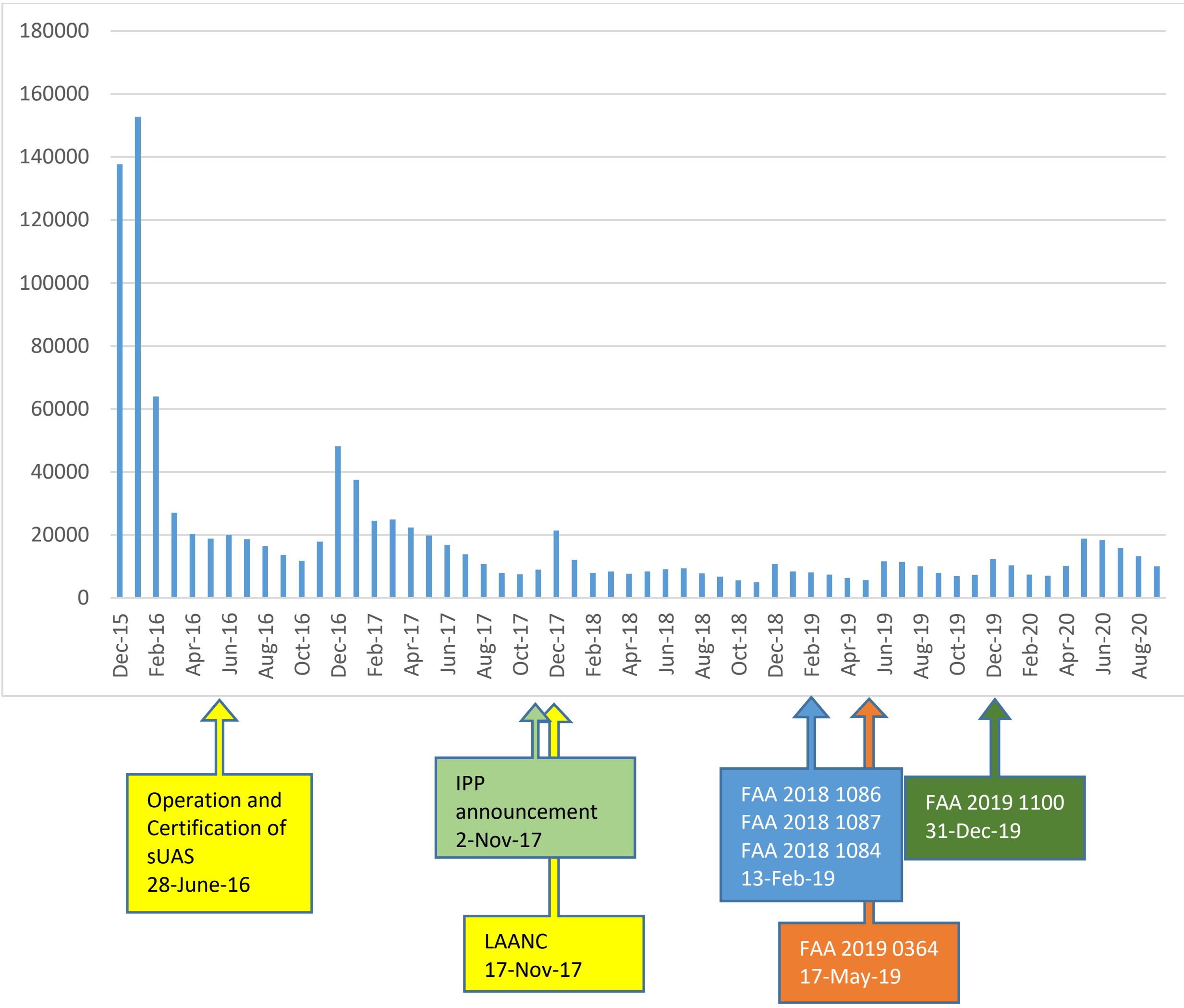


Figure 27. UAS registration numbers in the United States - Hobbyists (section 336) with NPRMs' Dates.

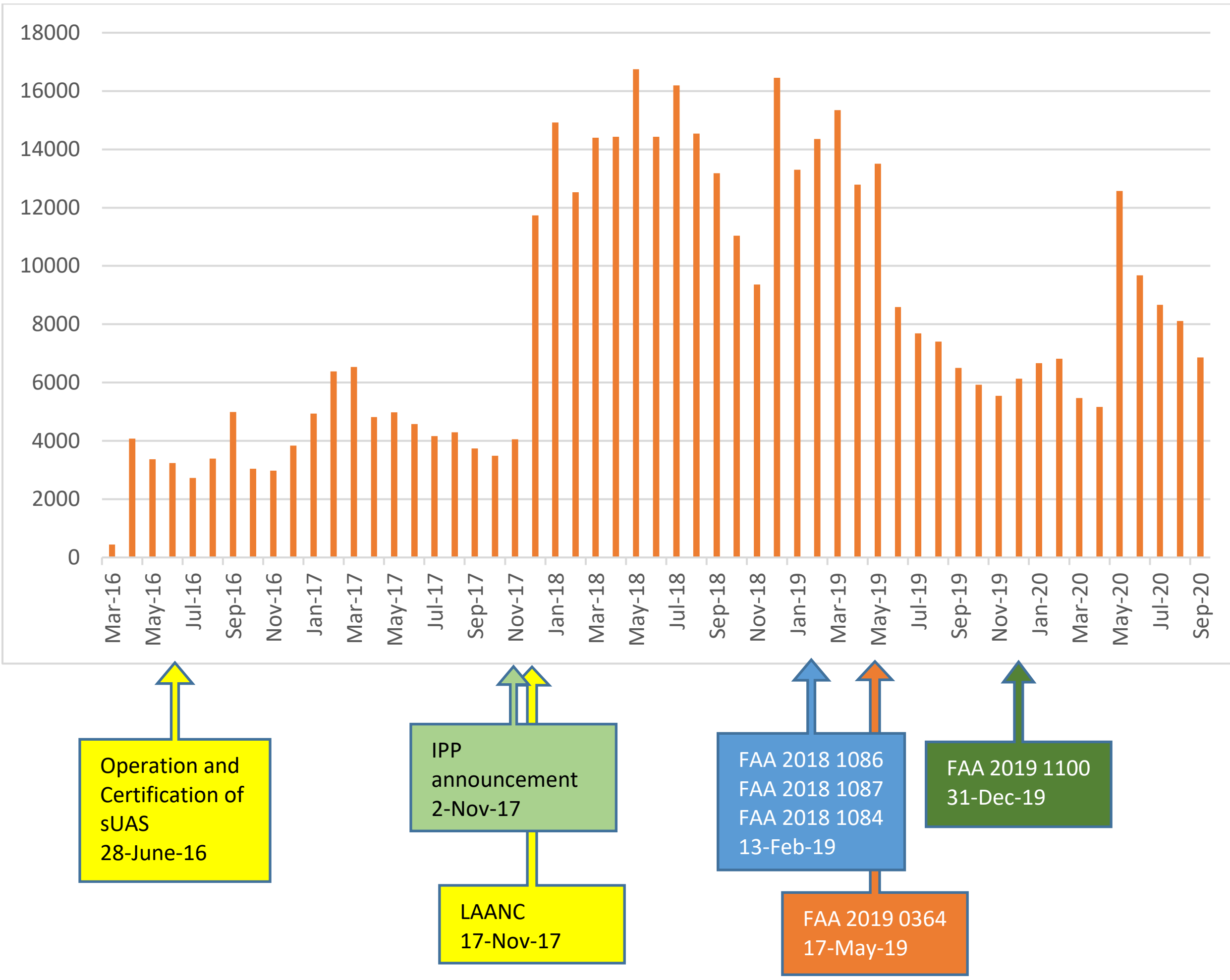


Figure 28. UAS registration numbers in the United States - Commercial (Part 107) with NPRMs' Dates.

Next, frequency analysis by zip code was conducted to compare across states, using heat maps. The heat maps present the number of registrations by zip code between December 2015 and September 2020, ranging from zip codes with the lowest number of registrations (represented by blue) to those with the highest number of registrations (represented by red). Areas without any overlaid color have zero registrations. Overall, our results show that the four states with the highest registrations are California, Florida, New York, and Texas for both hobbyists and commercial (see Figure 29 and
Figure 30). However, the heat maps present different stories between these two sectors. For Section 336 registrations, it appears that the registrations are very scattered with more activities on the east side, including the Northeast, Southeast, and Midwest regions. As shown in see Figure 29, many cities have more than 7,000 registrations by zip code, especially in Florida and New York. Texas, Maryland, Illinois, Ohio, Michigan, and North Carolina also have high registrations in several cities, including Dallas, Austin, Houston, Chicago, Detroit, Columbus, and Charlotte. On the other hand, on the west side, the registrations seem mainly taking place in the Southwest and Northwest regions. California has very high registrations, mainly in Los Angeles and San Francisco areas. In the Northeast, Seattle and Portland are two cities with the most registrations.

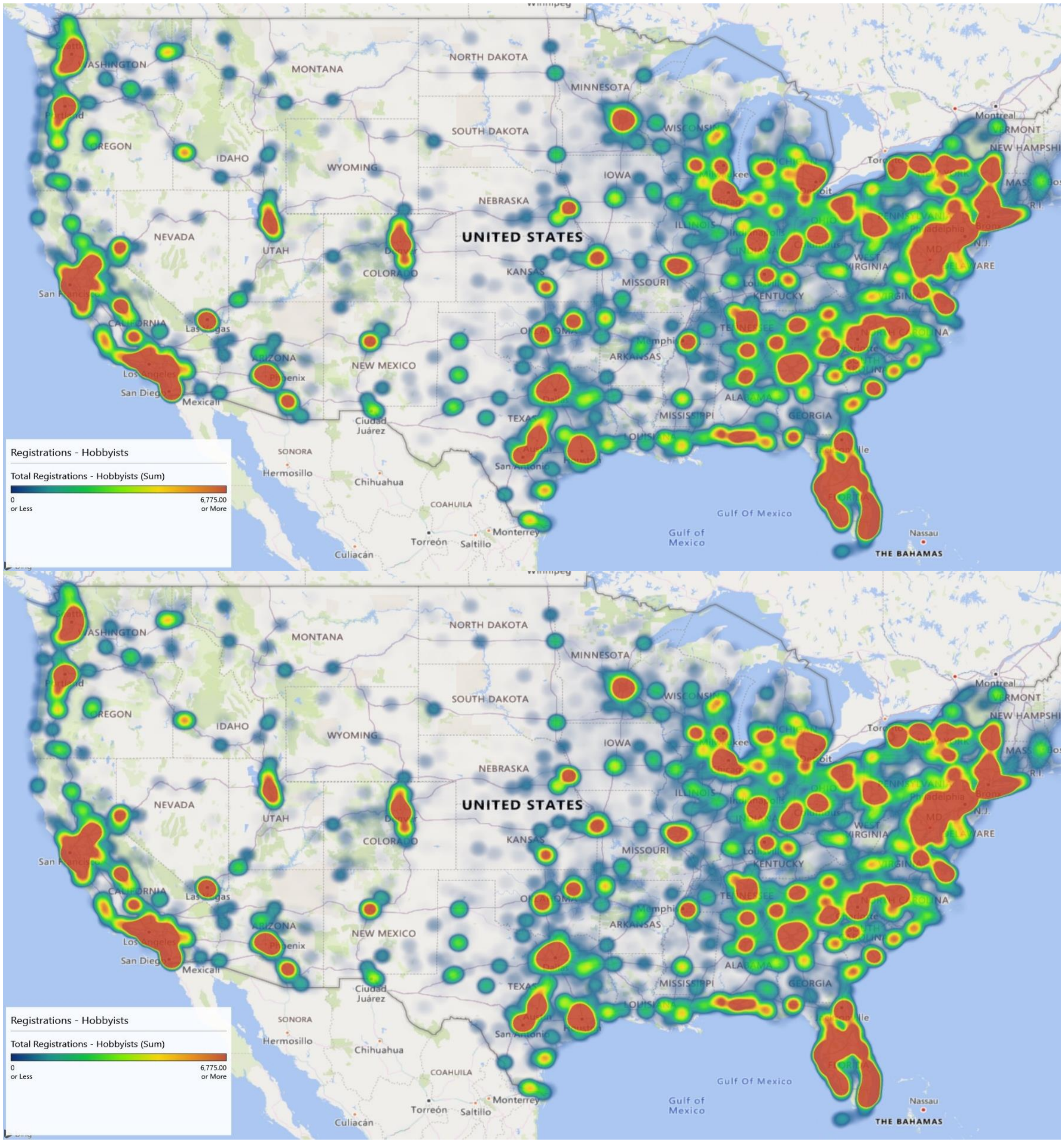


Figure 29. UAS Registrations Heat Map –Hobbyists (Section 336) from December 2015 to September 2020.

For Part 107, a similar pattern can be observed, but the registrations are more concentrated in certain urban areas. As presented in Figure 30, the east side still shows more activities, but it can be seen only few big cities have high registrations, above 10,000 registrations per zip code. They include New York City, Philadelphia, Baltimore, Orlando, Tampa, Miami, Charlotte, Dallas, and Houston. On the west side, less activities are observed. Major cities with most registrations include Los Angeles, San Francisco, Portland, and Seattle.

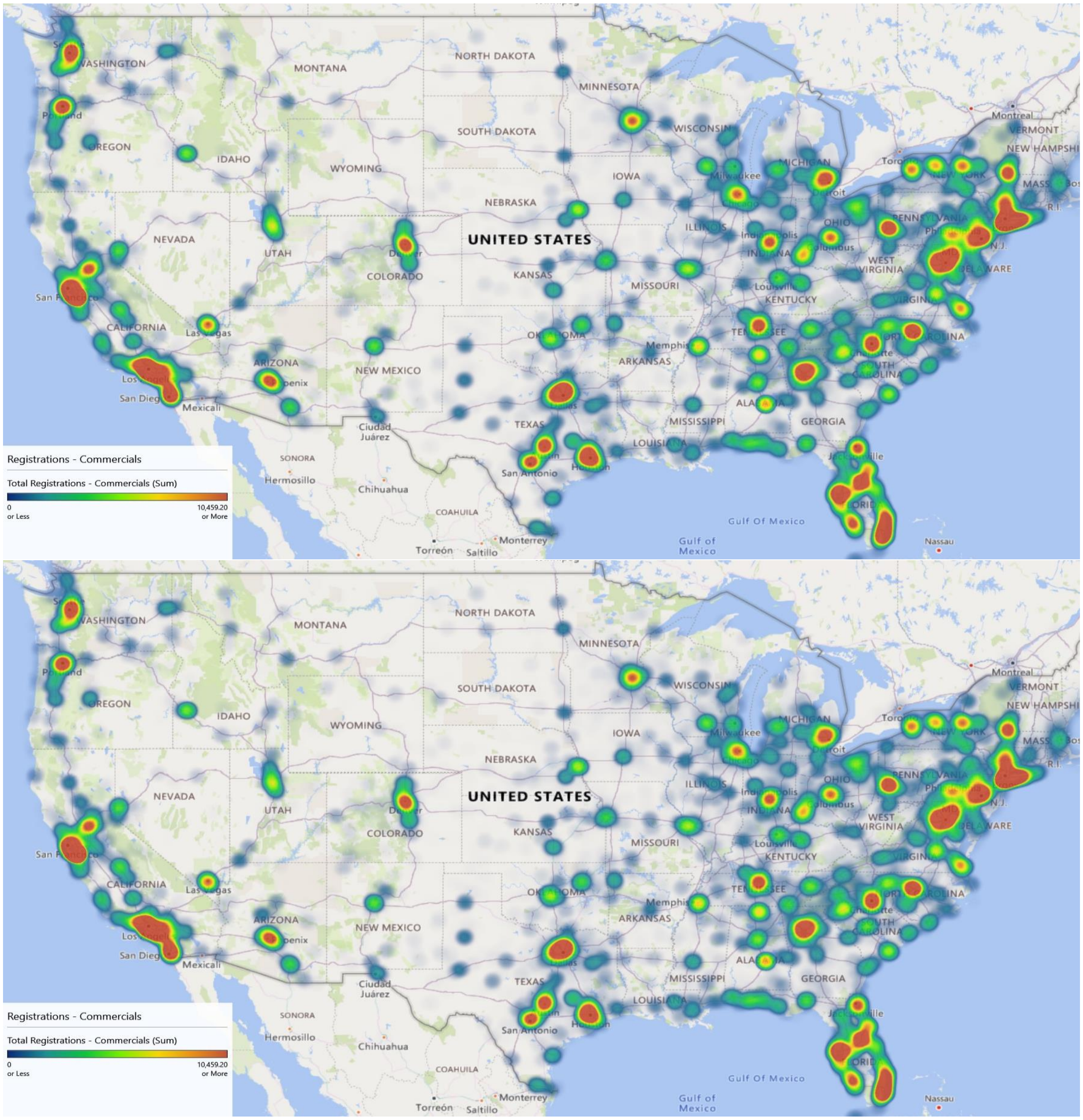


Figure 30. UAS Registrations Heat Map –Commercials (Part 107) from March 2016 to September 2020.

While Figure 29 and Figure 30 depict the total registration counts by state, Figures Figure 31 and Figure 32 present the number of UAS per capita within zip codes. In figure Figure 31, much of the map remains uncolored or lightly colored indicating across much of the United States only a small number of commercial UAS were registered. However, the map frequently shows higher per capita registrations around major US cities with the highest being near active commercial and research and development centers including the

San Franscisco Bay area, New York City metropolican area, Los Angeles, etc. The highest rate depicted was 3.58 UAS per person in the San Franscisco.

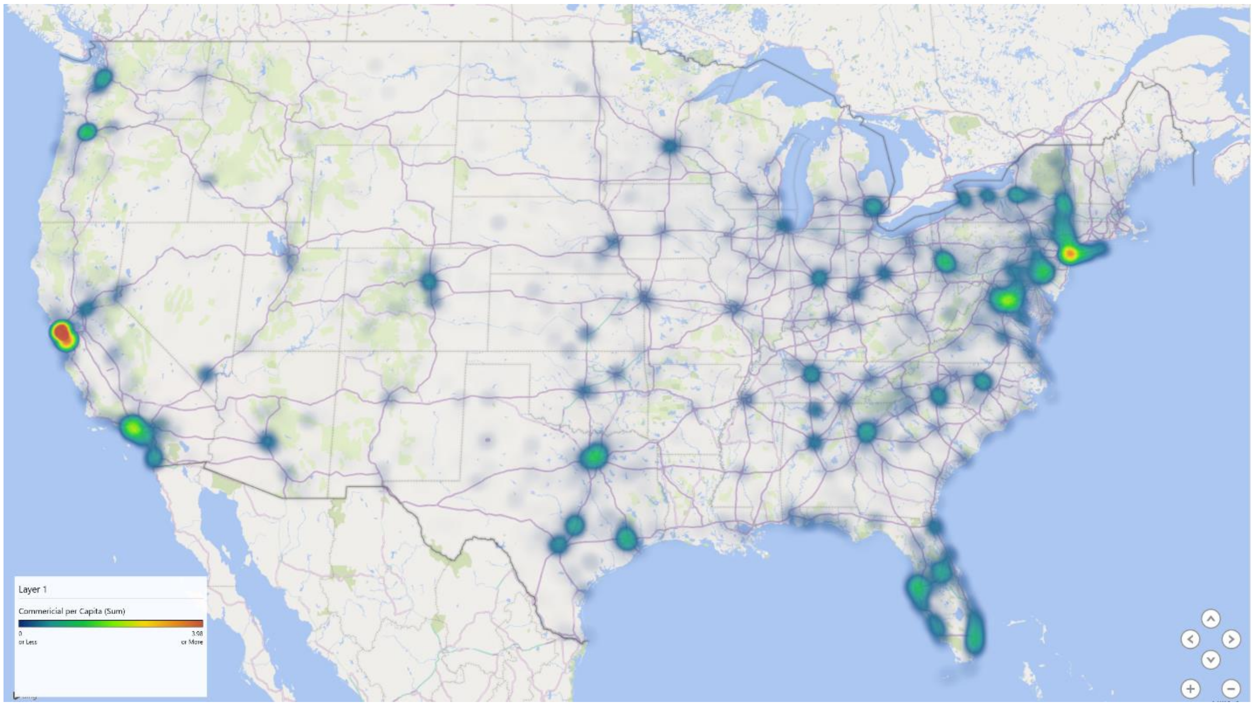


Figure 31. Heatmap of Commercial (Part 107) UAS Registrations per Capita (max score = 3.58 UAS per person).

Figure Figure 32's heatmap depicts a hobbyist registrations across US zip codes per capita with a maximum measure of 0.38 UAS per person. With much of the country colored in, it seems that UAS registrations occurred across the United States with large red areas indicating a higher trend for hobbyist registrations near cities.

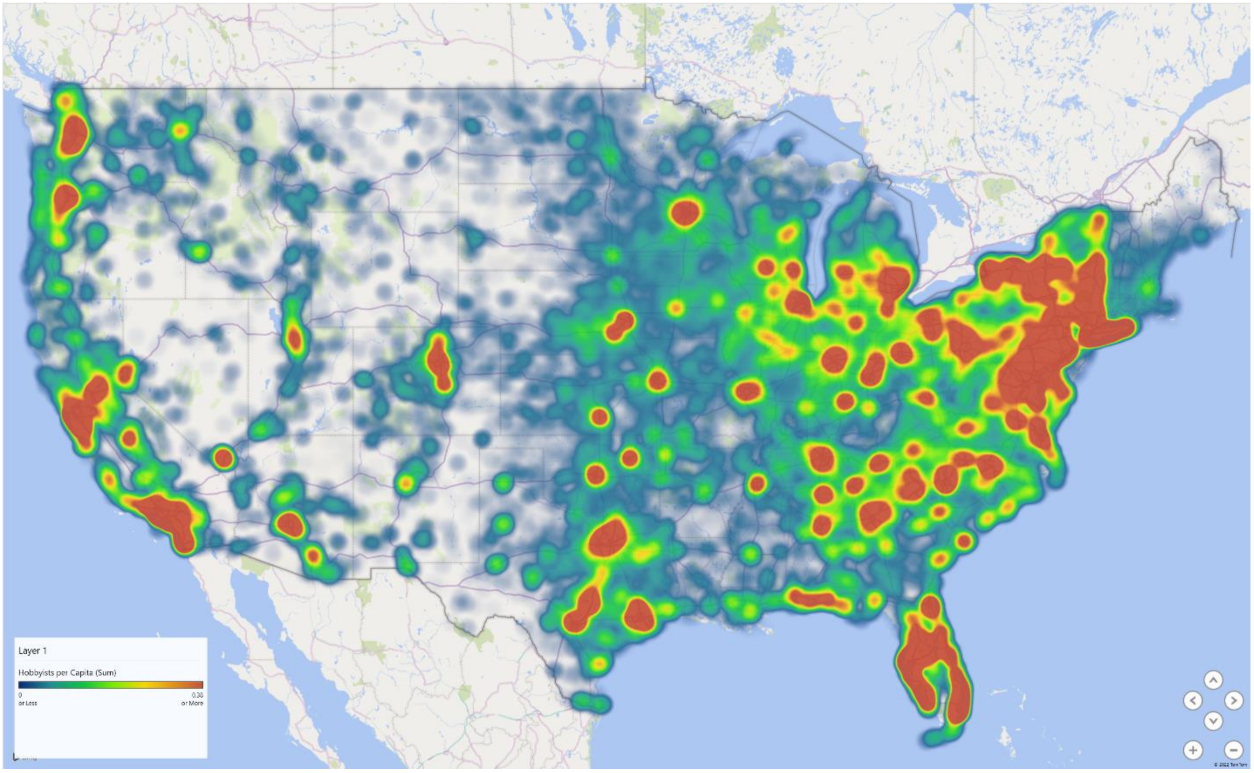


Figure 32. Heatmap of Hobbyist (Section 336) UAS Registrations per Capita (max = 0.38 UAS per Person).

6.4.1.4 UAS remote pilot certificates and Part 107 exam analysis results

This section focuses on the trend analysis for remote pilot certificates.

Figure 33 shows the number of pilot certificates issued under both 14 CFR Part 61 (requiring Part 61 certification and remote pilot certificate) and Part 107 (remote pilot certification only) decreased consistently from the third quarter of 2016 to the third quarter of 2019. On the other hand, certificates for remote pilots seem to fluctuate over time. These data show an increase in the first quarter of 2017 with more than 8,000 certificates per month. This increase could be explained by the Operation and Certification of sUAS requirements announced in June 2016. Then the certificates decreased slightly in the fourth quarter of 2017 before they started increasing and stayed high until the third quarter of 2017. The certificates reached the highest of more than 10,000 certificates in the second quarter of 2019. It is uncertain whether this increase could be related to the publication of four primary NPRMs in the first quarter of that year due to the lag in these rule-makings' effects, as described above. As mentioned previously, since the data only includes initial certification but not re-certification, the results in this section may only present the number of initial certificates, not the total number of certificates issued.

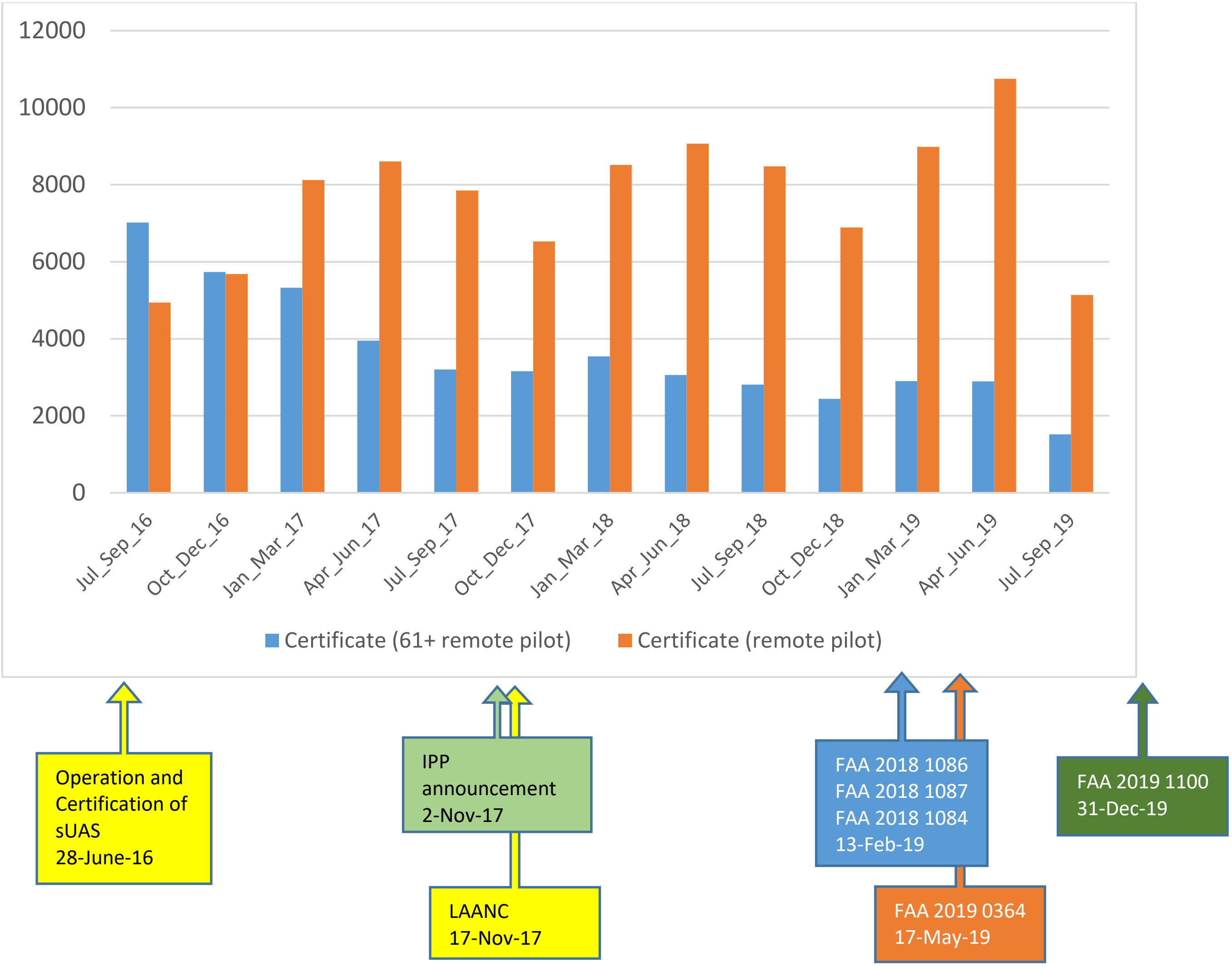


Figure 33. UAS Certificates in the United States with NPRMs' Dates.

Figure 34 shows the Part 107 exams. These numbers follow a similar pattern with remote pilot certificates, as presented above. Exams have a slight fluctuation between the third quarter of 2016 and the fourth quarter of 2018. The numbers of initial exams increased until June 2019, then it decreased approaching September 2019, while the numbers of current exams (i.e. exams for recertification/currency) grew from June 2018 to June 2019, then decreased approaching September 2019. The increase of exams in early 2017 could be due to the announcement of the Operations and Certification of sUAS. Additionally, the increase of exams in early 2018 could be due to the launch of LAANC in late 2017. It appears that Part 107 exams were greatest in the second quarter of 2019 prior to beginning a downward decline. It appears that the publications of NPRMs in the first quarter of 2019 may correlate with the number of exams completed since the total number of exams increased significantly after the publications.

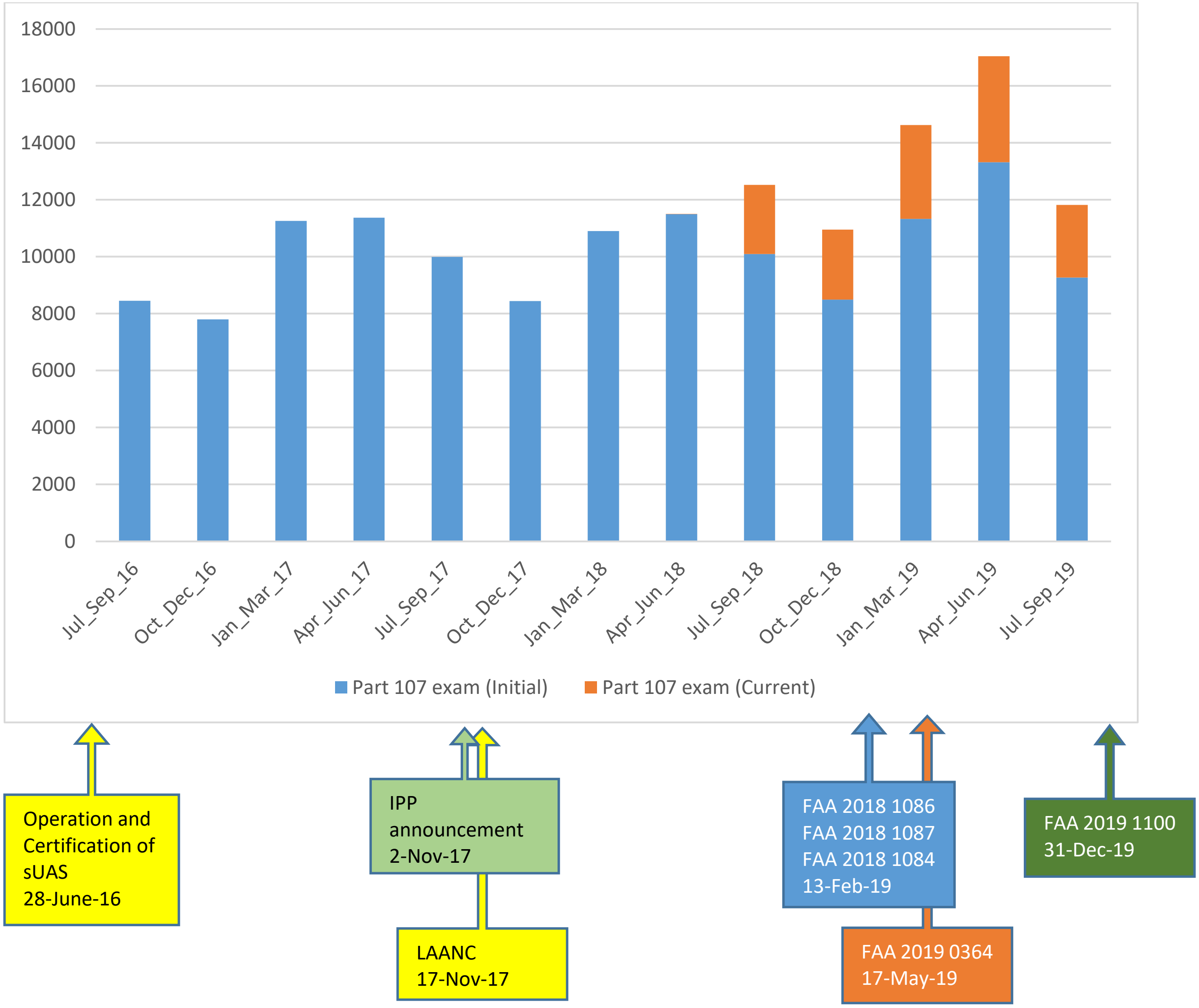


Figure 34. Number of Part 107 Exams.

Figure 35 shows four elements of the Part 107 exam results, referred to as 1) Pass (Initial), 2) Fail (Initial), 3) Pass (Current), and 4) Fail (Current). First, the Pass (Initial) results accounted for most of the data, and the number fluctuated over time. It peaked at approximately 12,000 passes in the second quarter of 2019. The other two peaks occurred in the first quarter of 2017 and the second quarter of 2018 with more than 10,000 passes per month. Second, the Fail (Initial) results were much lower and almost stabilized over time. We only noticed a slight increase in the second quarter of 2019, and then it decreased again in the third quarter of the same year. Third, the Pass (Current) results increased from September 2018 to June 2019, then declined gradually to September 2019. Finally, the Fail (Current) results remained low, with a slight increase in the second quarter of 2019.

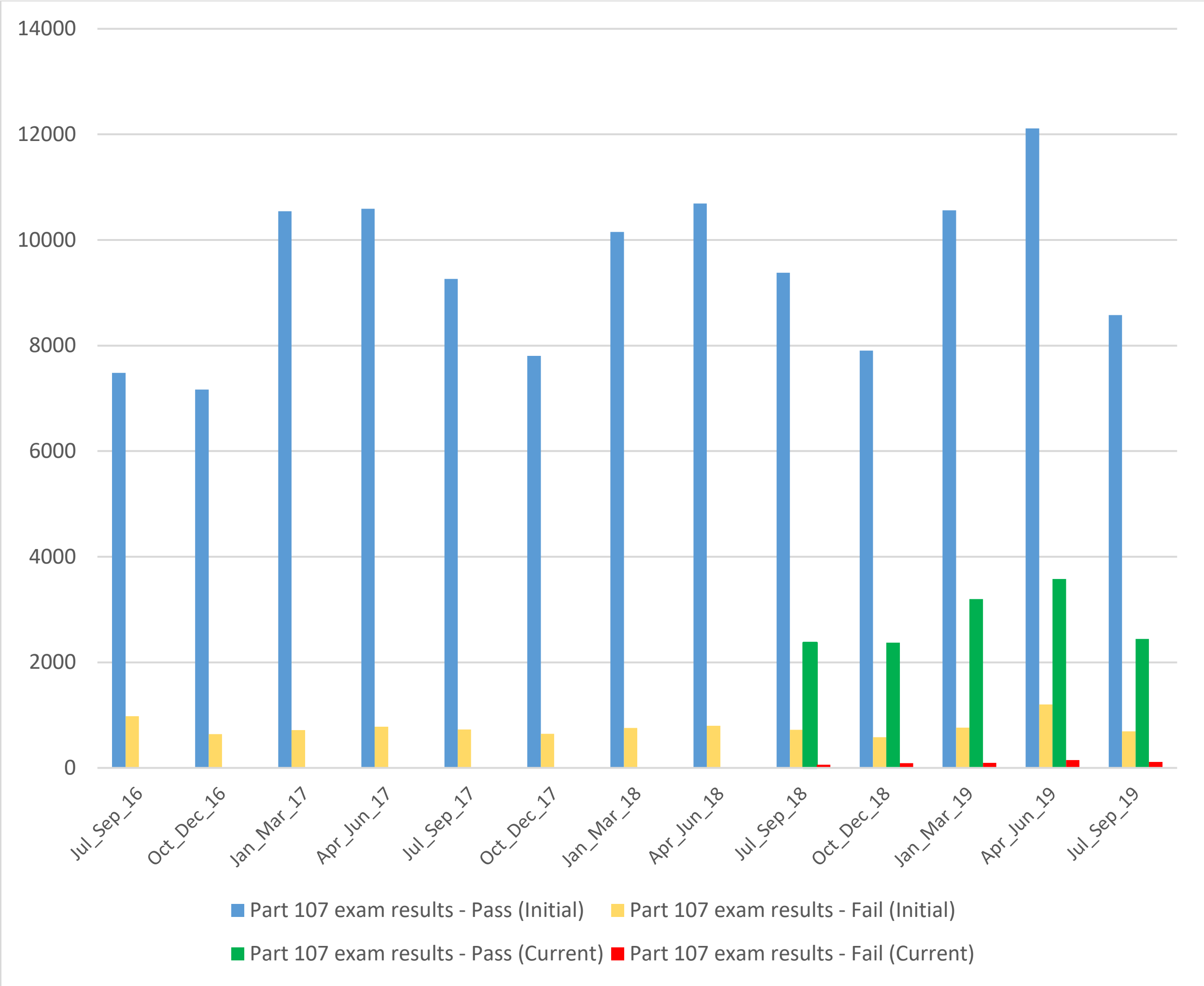


Figure 35. Part 107 Exam Results.

6.4.2 UAS Waivers

6.4.2.1 Introduction to UAS waiver applications

According to FAA Part 107, operators of UAS weighing 55 pounds or less must fly under 400 feet, within visual line of sight and only during daylight hours. However, when operators want to operate UAS in a manner that is not permitted under Part 107107, such as to conduct beyond the line of sight or nighttime operations, they need to obtain a waiver from the FAA, which allows UAS pilots to deviate from certain rules under Part 107 by demonstrating they can still fly safely using alternative methods (AUVSI, 2020; FAA, 2019). More specifically, the applicants must have a waiver when they want to operate a sUAS contrary to the rules in Part 107 under the waivable operations listed below in Table 14.

Table 14. Part 107 waiver applications requirements.

The applicants want to…	Part 107 regulation they need a waiver from…
Fly a UAS from a moving aircraft or a vehicle in populated areas	§ 107.25 – Operation from a Moving Vehicle or Aircraft
Fly a UAS at night	§ 107.29 – Daylight Operations
Fly a UAS beyond your ability to determine its orientation with an unaided vision clearly	§ 107.31 – Visual Line of Sight Aircraft Operation
User a visual observer without following all visual observer requirements	§ 107.33 – Visual Observer
Fly multiple UAS with only one remote pilot	§ 107.35 – Operation of Multiple Small UAS
Fly a UAS without having to give way to other aircraft	§ 107.37(a) – Yielding Right of Way
Fly a UAS over a person/people	§ 107.39 – Operation Over People
Fly a UAS: • Over 100 miles per hour ground speed • Over 400 feet above ground level (AGL) • With less than three statute miles of visibility • Within 500 feet vertically or 2000 feet horizontally from clouds	§ 107.51 – Operating limitations for Small Unmanned Aircraft

Note. Adapted from Part 107 Waivers (FAA, 2019)

6.4.2.2 Data Analysis Method

Trend analysis was conducted using descriptive statistical analysis and visualization to examine the patterns of waiver applications over time. Since detailed UAS waiver information has been presented in Tasks 1-1 and 1-2, only selected information is presented in this section to avoid duplication. The total number of waivers over time was presented on a bar chart along with publication dates of NPRMs. The chart shows the pattern of waivers from January 2016 to April 2020. Additionally, waivers were also broken down by IPP waivers and non-IPP waivers. Since IPP-waivers had started in August 2018, the trend of these data is presented separately from non-IPP waivers. Then, the waivers by regulations are presented along with approved and denied applications for each type of waiver regulation using descriptive statistics and bar charts. A similar method was used to group the type of waived UAS operations, including approved and denied applications. Lastly, the type of request is also presented along with the number of each type.

6.4.2.3 Analysis Results

Figure 36 shows the total number of UAS waivers over time, along with LAANC and NPRM dates. Furthermore, Figure 37 and Figure 38 present the number of IPP and non-IPP waivers, respectively. It appears that the total number of UAS waivers fluctuated between August 2016 and 2020. The waivers reached a high number in April 2017 and then decreased toward the end of the year. It is worth noting that the waivers started to increase consistently afterward, which could be explained by the announcement of LAANC in November 2017. Then, the waivers continued to increase and stayed above 100 waivers per month, except for several decreases in January and August 2019. The waivers reached a peak of about 200 waivers per month in April 2020. Then, the UAS waivers decreased towards July 2020. The pattern does not appear to be seasonal. Nonetheless, the waivers do increase after the publication of four major NPRMs in early 2019, and we noticed a spike in the number of waivers after the publication of the latest NPRM pertaining to Part 107 remote pilots. It is uncertain whether NPRMs cause higher waiver applications, which lead to higher approved waivers, due to a possible lag of NPRMs' effects, as discussed before; however, other factors could be responsible for this rise.

Figure 37 shows that IPP UAS Waivers fluctuated between August 2018 and July 2019. The numbers of waivers surged in August 2019 and then dropped significantly in September 2019. Note that IPP waivers only exist since August 2018. Finally, the Non-IPP UAS Waivers in Figure 38 fluctuated between January 2016 and May 2020. There was a peak in October 2019 and in March 2020. Following the March 2020 peak, the numbers of Non-IPP UAS Waivers show a steady decline.

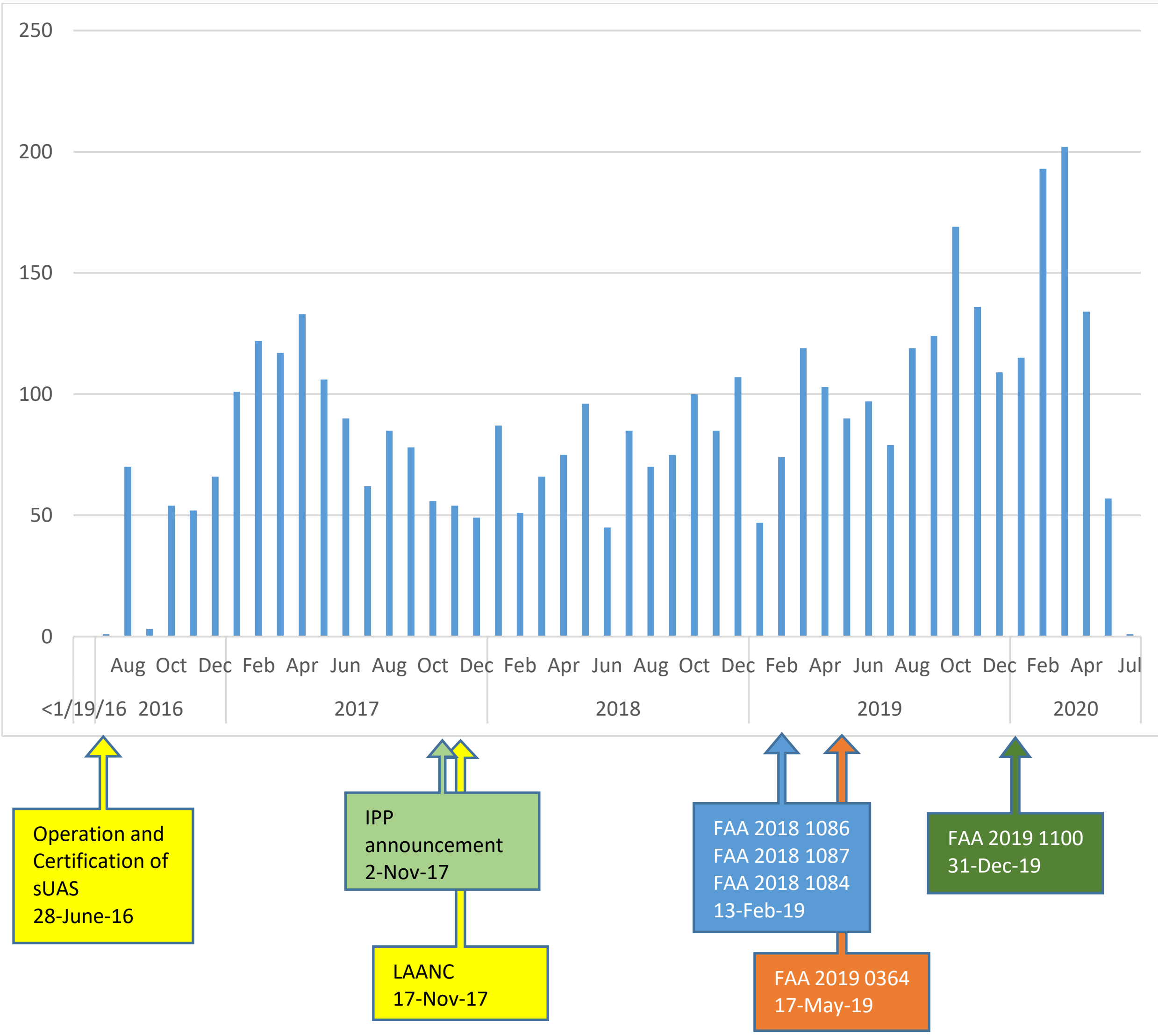


Figure 36: Total number of waivers issued monthly with UAS integration milestones labeled.

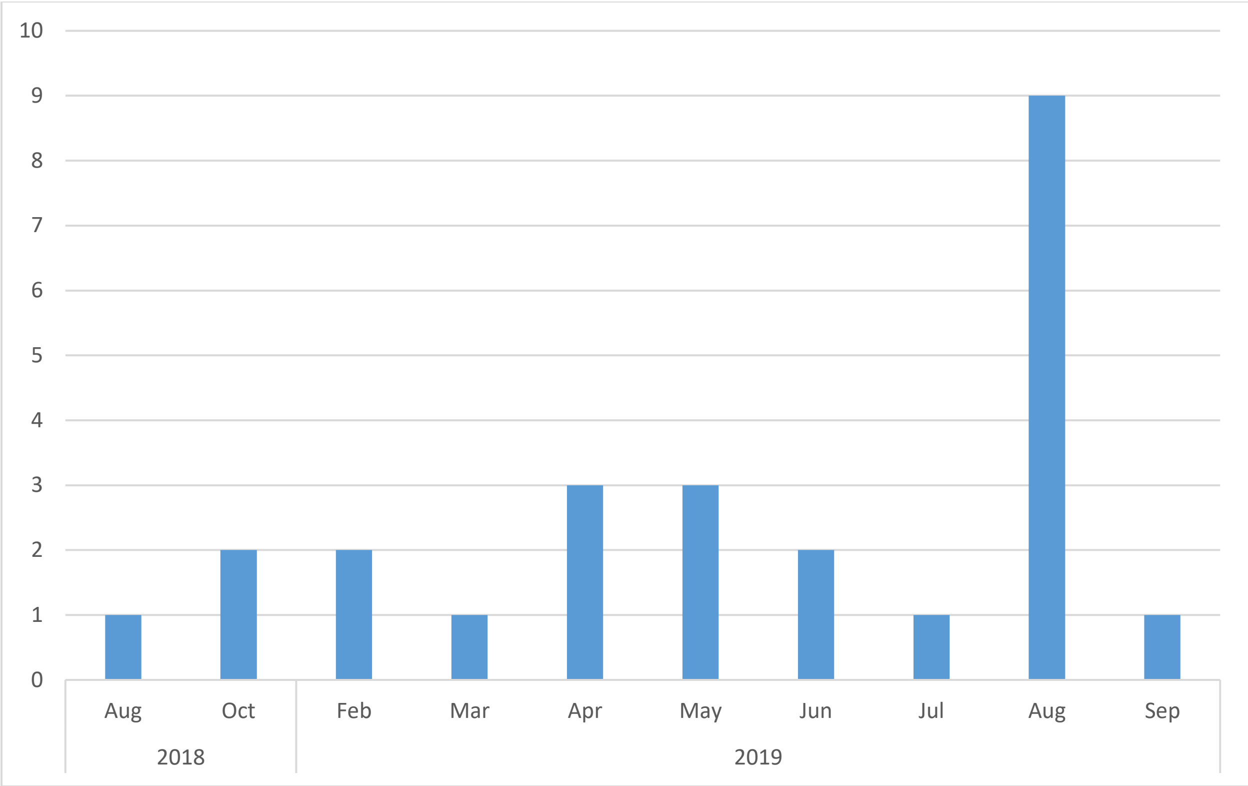


Figure 37. IPP UAS Waivers.

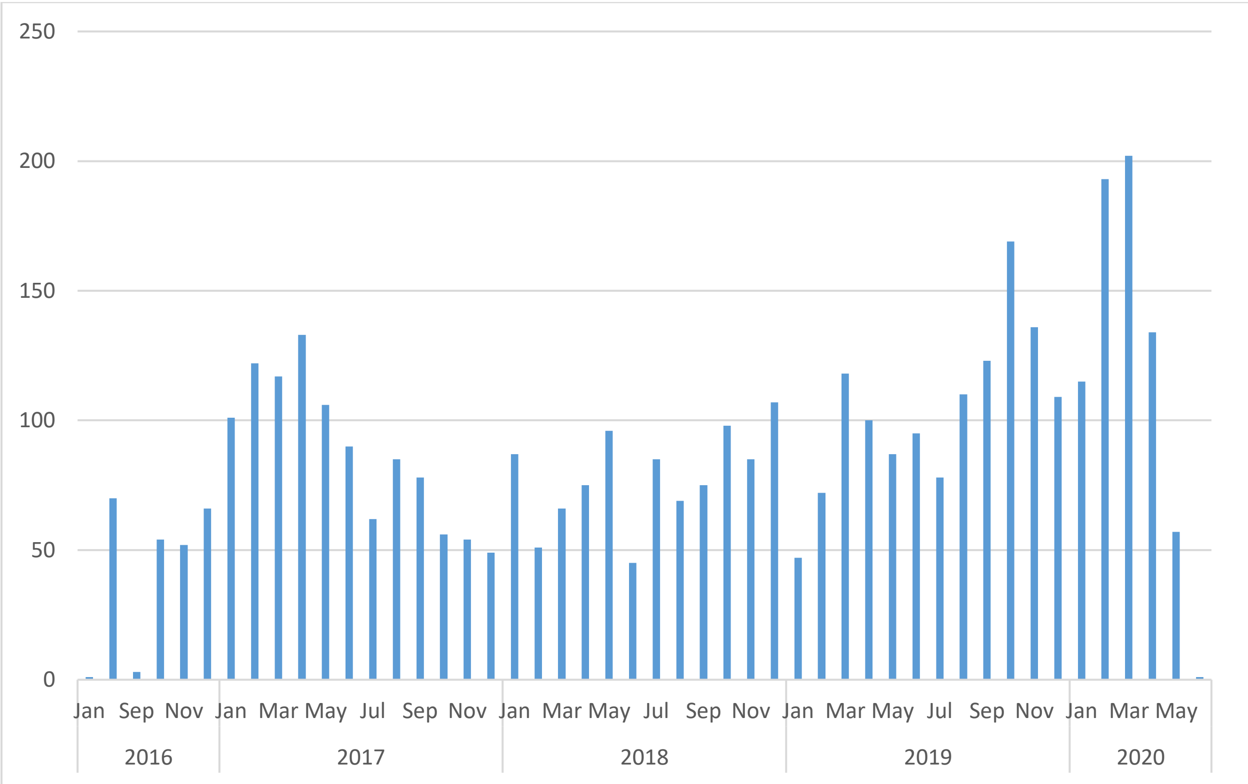


Figure 38. Non-IPP UAS Waivers.

Figure 37 shows the waiver request results by waiver operation type from December 2016 to August 2020... It shows that in general, the number of requests denied was far greater than the number of requests approved. To illustrate, of the 1,016 the Part 107.33 waivers submitted, about 94% were denied. Almost 100% of the Part 107.25 waivers and 97% of the Part 107.31 waivers were denied. Similarly, about 95% of the Part 107.51(b) waivers and 96% of the Part 107.39 waivers were denied. Part 107.29 is the one with the lowest denial percentage, only 70%. The rather high denial rate could be a result of a lack of operational hazards and proposed risk mitigation strategies in the waiver applications. As presented in Section 4.4, waiver requests do not provide sufficient information regarding risk assessment and risk control, two important steps in the SRM process. Accordingly, the FAA could not make a complete safety analysis and would disapprove of the applicant's application based on insufficient information.

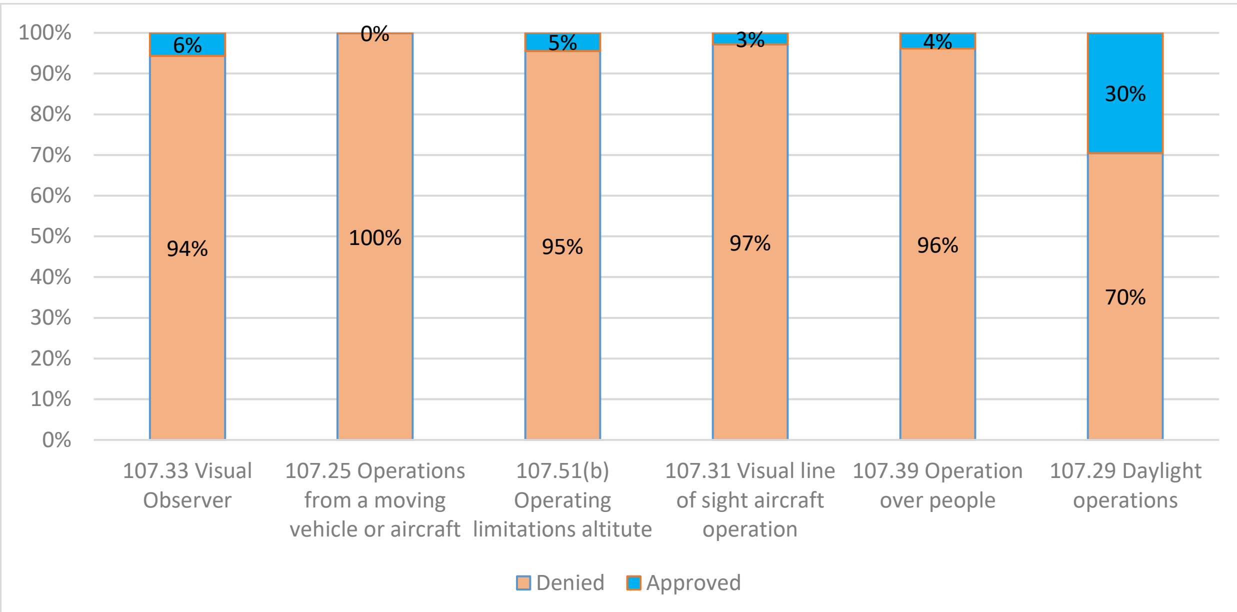


Figure 39. Waiver request results by operation type from December 2016 to August 2020
(Source: FAA internal Part 107 waiver application information)

The bar chart in Figure 40 shows the types of waiver requests submitted and processes initiated. The type of process for which the highest number of waiver requests were submitted was simple/routine processes (14,844 requests), followed by highly complex process (976 requests), moderately complex with 802, and Undetermined with 636.

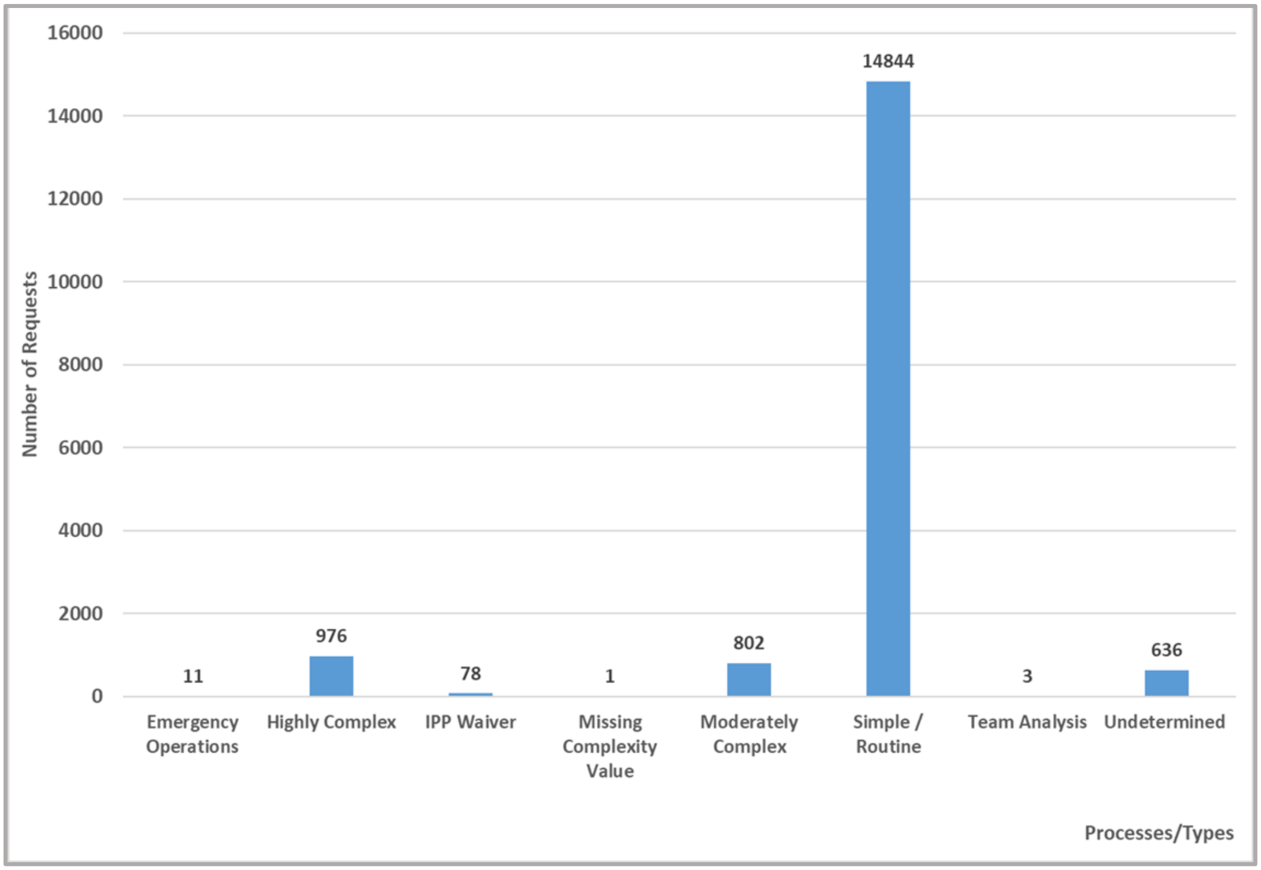


Figure 40. Types of Requests Submitted and Processes Initiated from December 2016 to August 2020 (Source: FAA internal Part 107 waiver application information)

6.4.3 UAS Test Site Operations

To conduct test flights, the FAA designated six UAS Test Sites, which became operational in 2014. In 2016, the FAA added a seventh test site as mandated by the FAA Extension, Safety and Security Act of 2016 (FESSA 2016). Table 15 shows the seven FAA UAS Test Sites (FAA, 2020b).

Table 15. FAA UAS Test Sites.

Site Name	State
Griffiss International Airport	NY
New Mexico State University	NM
North Dakota Department of Commerce	ND
State of Nevada	NV
Texas A&M University-Corpus Christi	TX
University of Alaska Fairbanks	AK
Virginia Polytechnic Institute & State University	VA

The introduction of MLS data at test sites is provided in Section 2.4.3 with the details of all variables and percentage of complete data. In this section, we conducted the trend analysis for MLS operations and MLS incidents/accidents from April 2015 to September 2019. Descriptive statistics and visualization were used to analyze the data and present the results, including number of operations over time, by aircraft type, weight, operating altitude, test sites, flight hours, line of sign mode, and airspace class.

6.4.3.1 Mission Logging System (MLS) Operations Trend Analysis

Figure 41 shows the total number of MLS operations from 2015 onward. Most MLS flight operations occurred in the third quarter of 2016, followed by quarter 2 of the same year. Then, the operations initially decreased before stabilizing through the second quarter of 2018, when they started to decrease further. We can also note an increase in operations in the second quarter of 2019, and a sharp fall in quarter 3 of that year. Figure 42 and Figure 43 show the number of MLS operations by aircraft type and operating altitudes, respectively. The AeroVironment Puma aircraft type had the most operations of 2,154 flights. In terms of operating altitude, it appears that most of flights (1,100 flights) were at the 900 ft altitude.

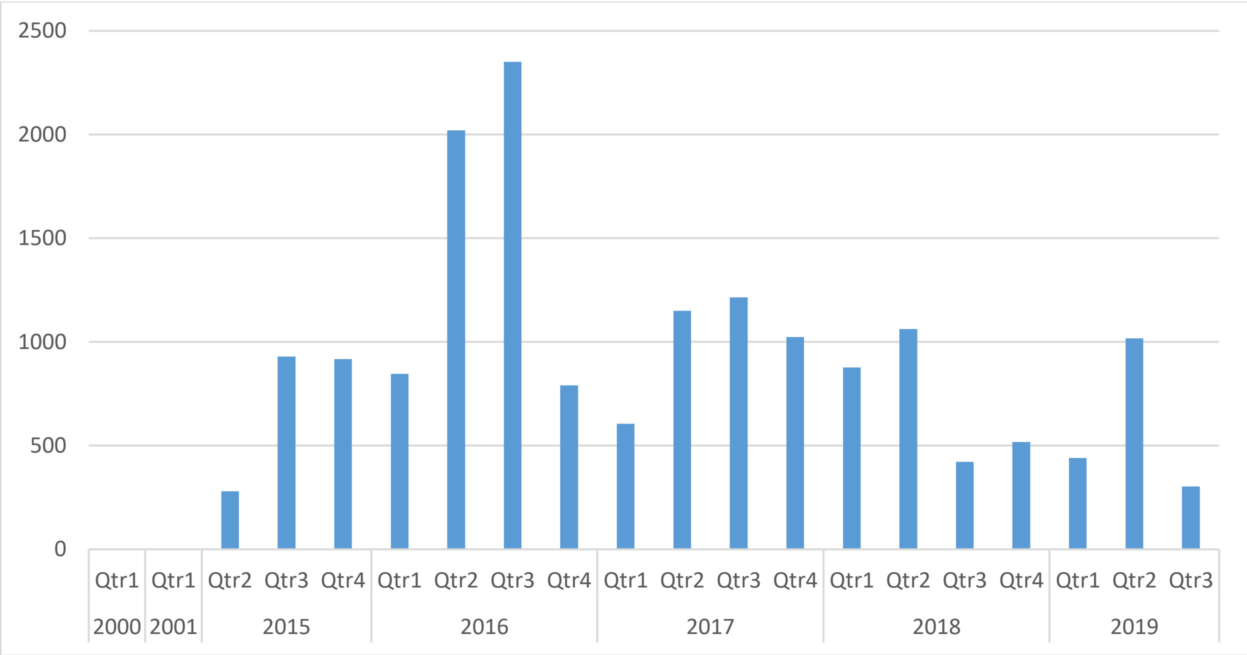


Figure 41. MLS operations over time.

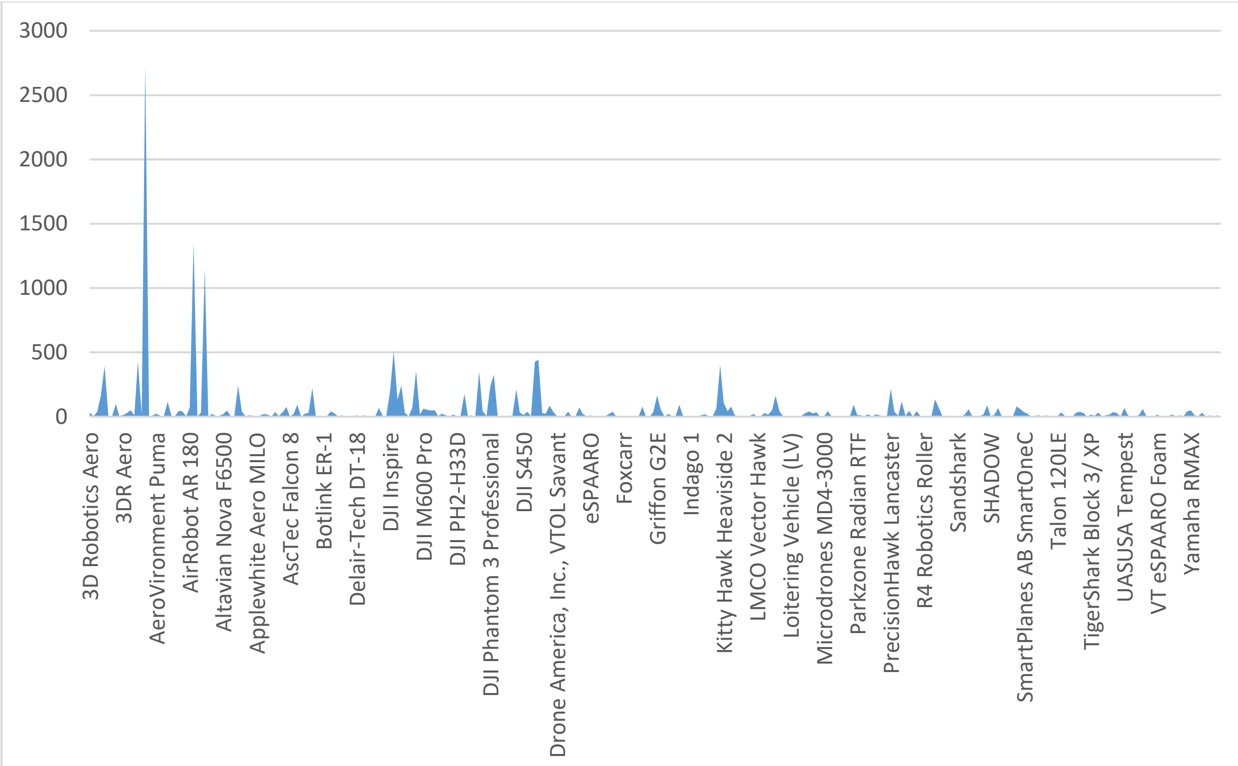


Figure 42. Number of MLS operations by aircraft type.

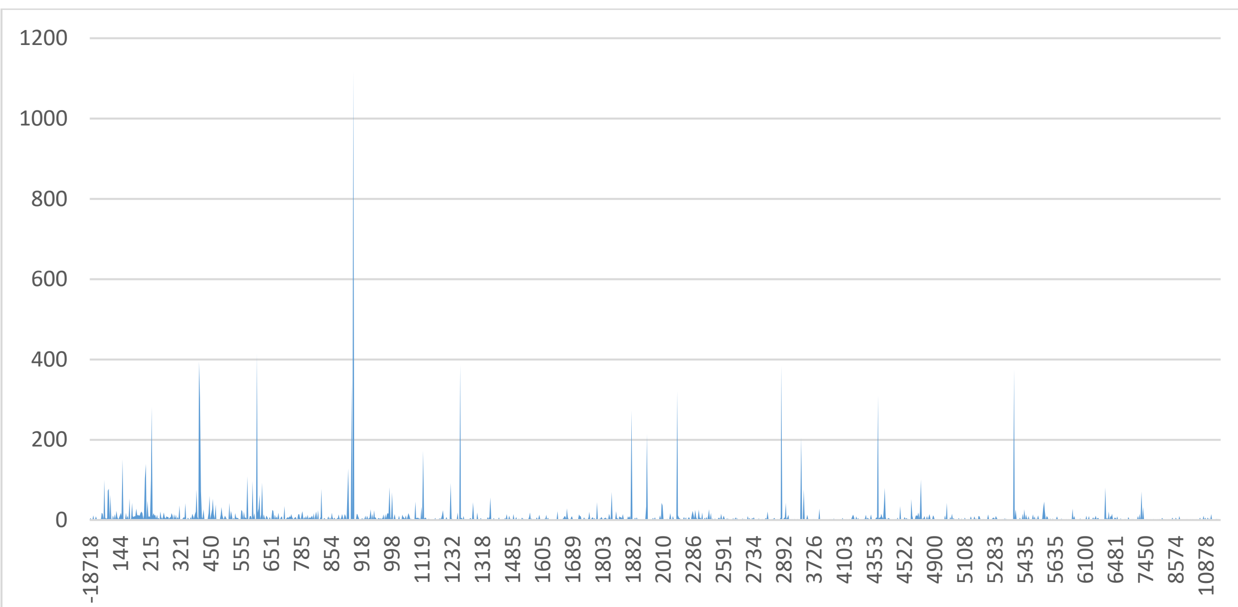


Figure 43. Number of MLS operations by operating altitude.

The data in Figure 44 shows that the number of operations per month by test site fluctuated from month-to-month between 2015 and 2020. The numbers increased from June 2016 to July 2016, with the highest value of approximately 1,010. The second peak occurred in October 2019 with a value of roughly 850, after which the totals decrease through February 2020.

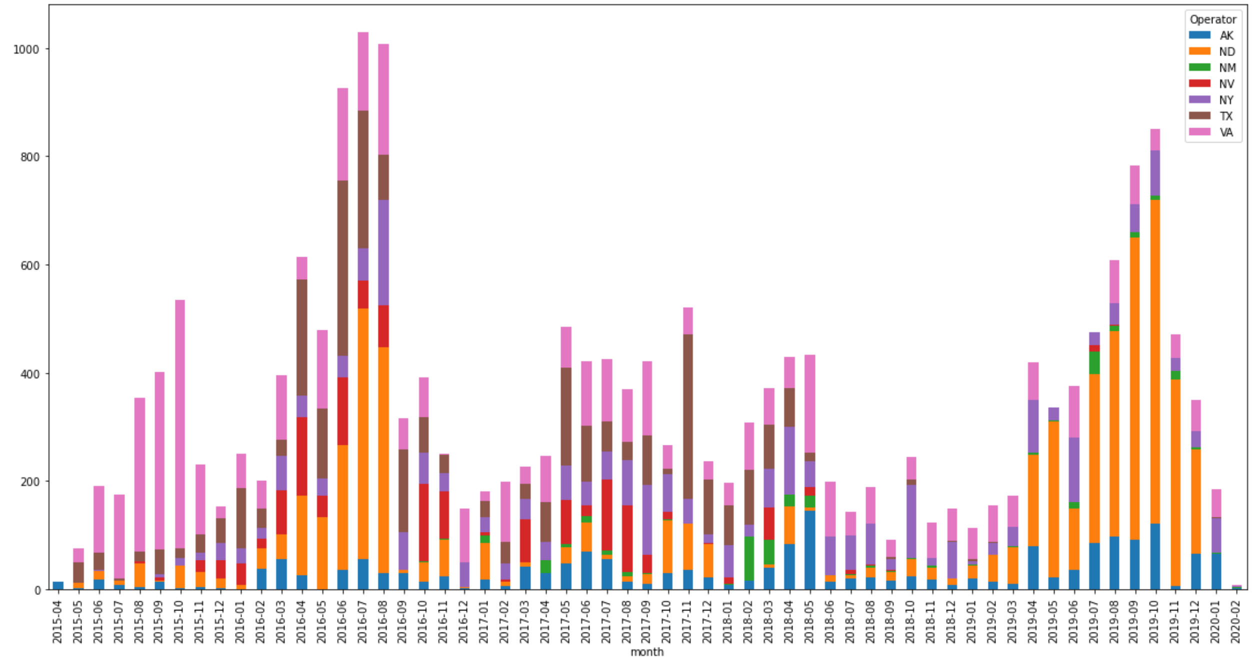


Figure 44. MLS operations by test site.

Figure 45 shows that the number of operations by UAS weight category fluctuated from month-to-month between 2015 and 2020. The totals increased from June 2016 to July 2016, with the highest value of approximately 1010. The second peak occurred in October 2019 with a value of about 850, and then the number decreases towards February 2020. It can be seen that most flights from April 2015 to March 2019 are sUAS, while most flights from April 2019 to January 2020 are large UAS.

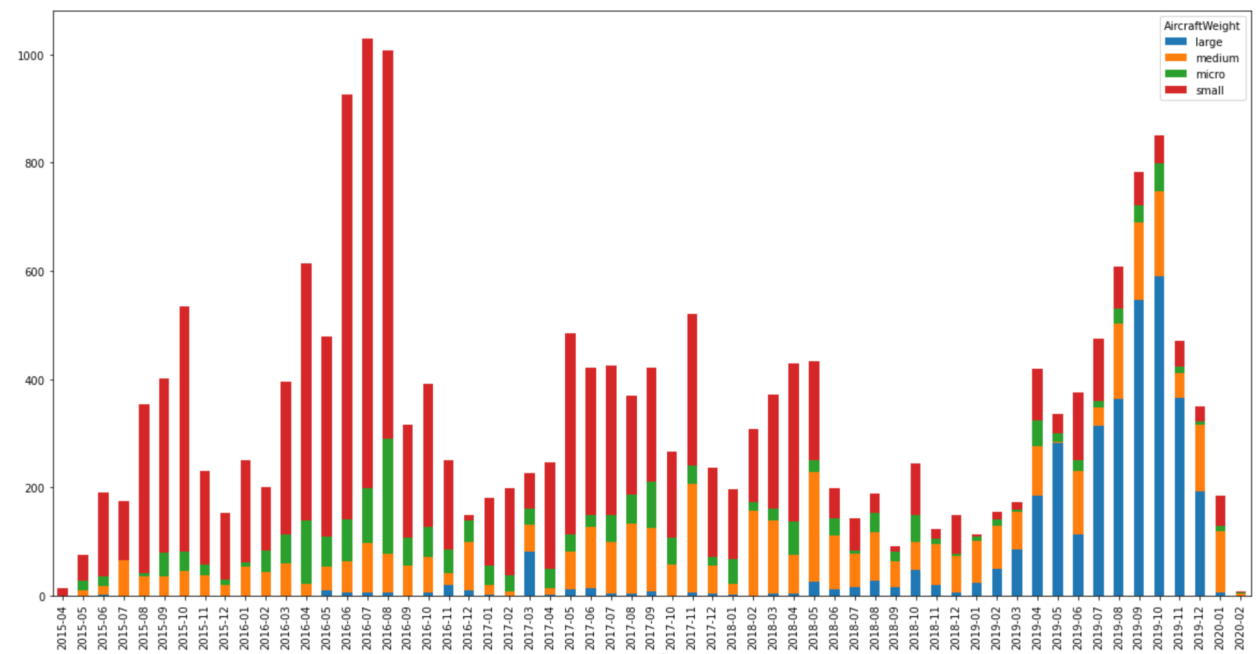


Figure 45. MLS operations by weight category (micro: under 5 lbs.; small: 5-55 lbs.; medium: 55-300 lbs.; large: 300+ lbs.).

The data in Figure 46 shows that the number of operations in the LOS category (Los, EVLoS, BLoS) fluctuated from month-to-month between 2015 and 2020. The graph indicates the operations increased from June 2016 to July 2016, with the highest value of approximately 890. The second peak occurred in October 2019, with a value of about 800.

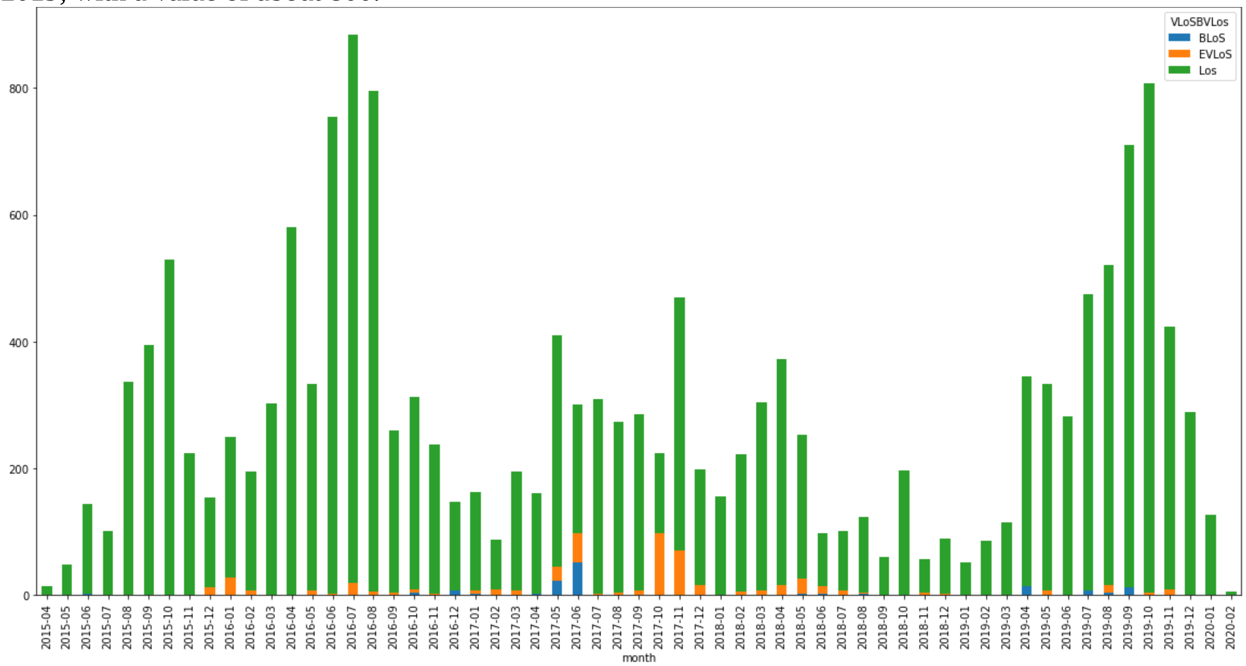


Figure 46. MLS operation by LOS category.

Figure 47 shows that the total flight hours per month of MLS operations fluctuated from month-to-month between 2015 and 2020. The number of flight hours surged in August 2018, with the highest value of approximately 1,000.

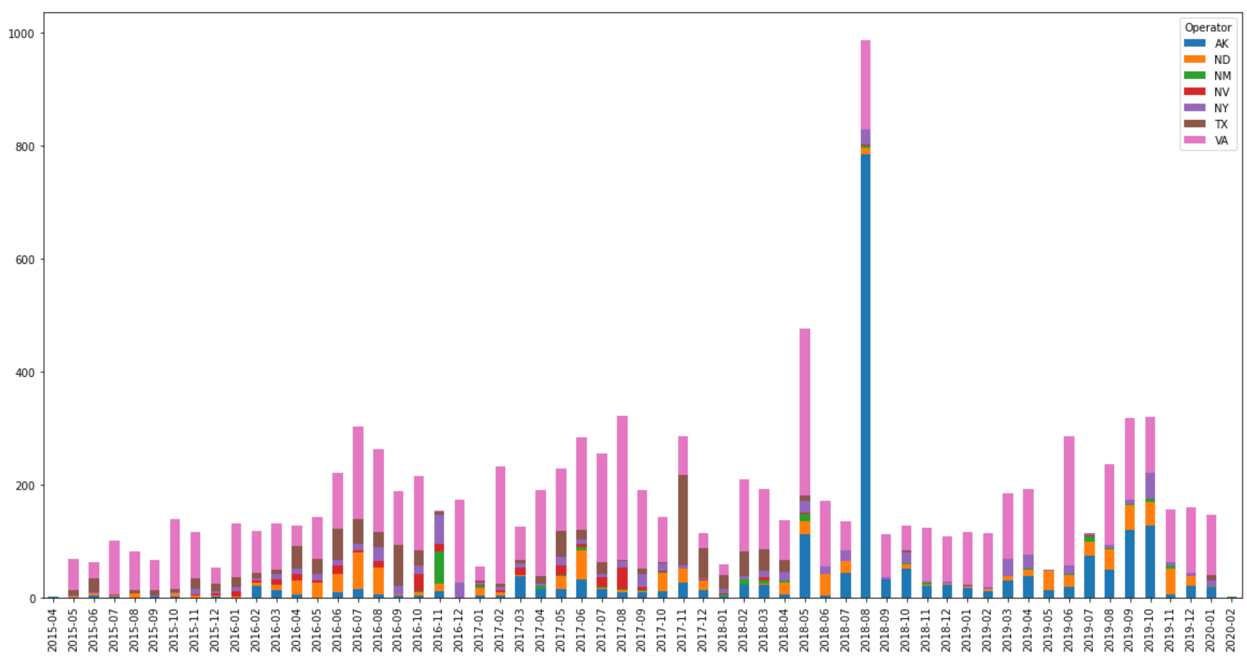


Figure 47. MLS total flight hours by test site.

The data in Figure 48 shows that the summary MLS-total flight hours by weight category fluctuated from month-to-month between 2015 and 2020. The graph increased suddenly and forcefully in August 2018 with the highest value of approximately 1000.

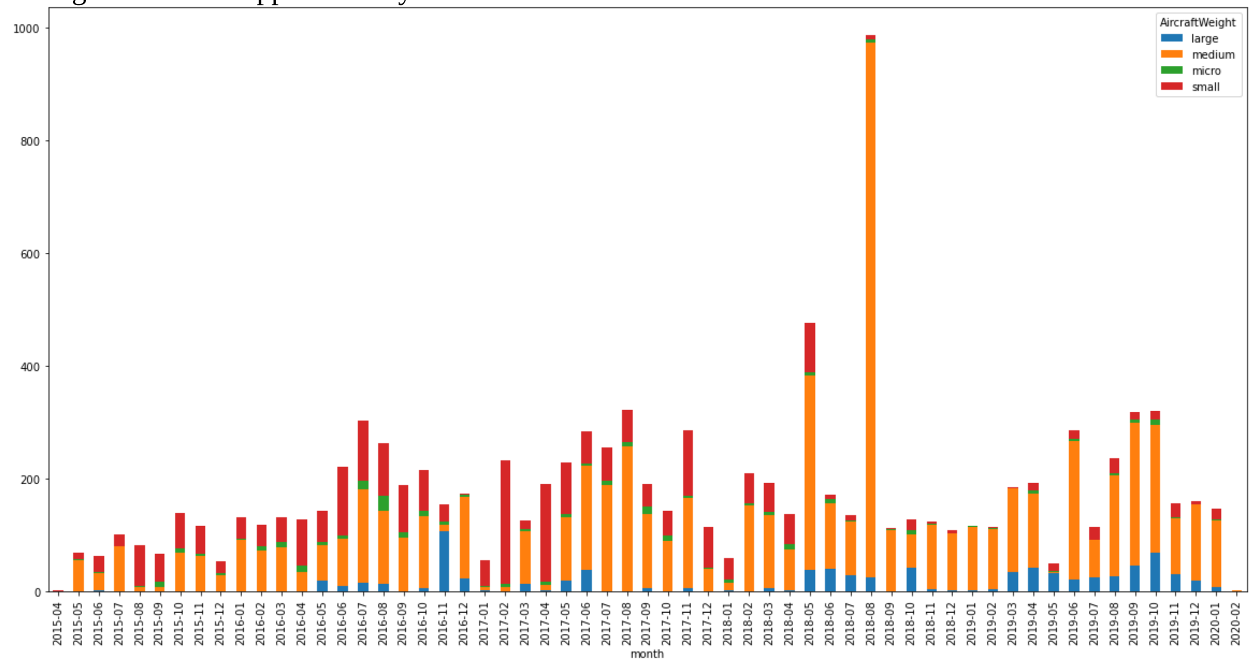
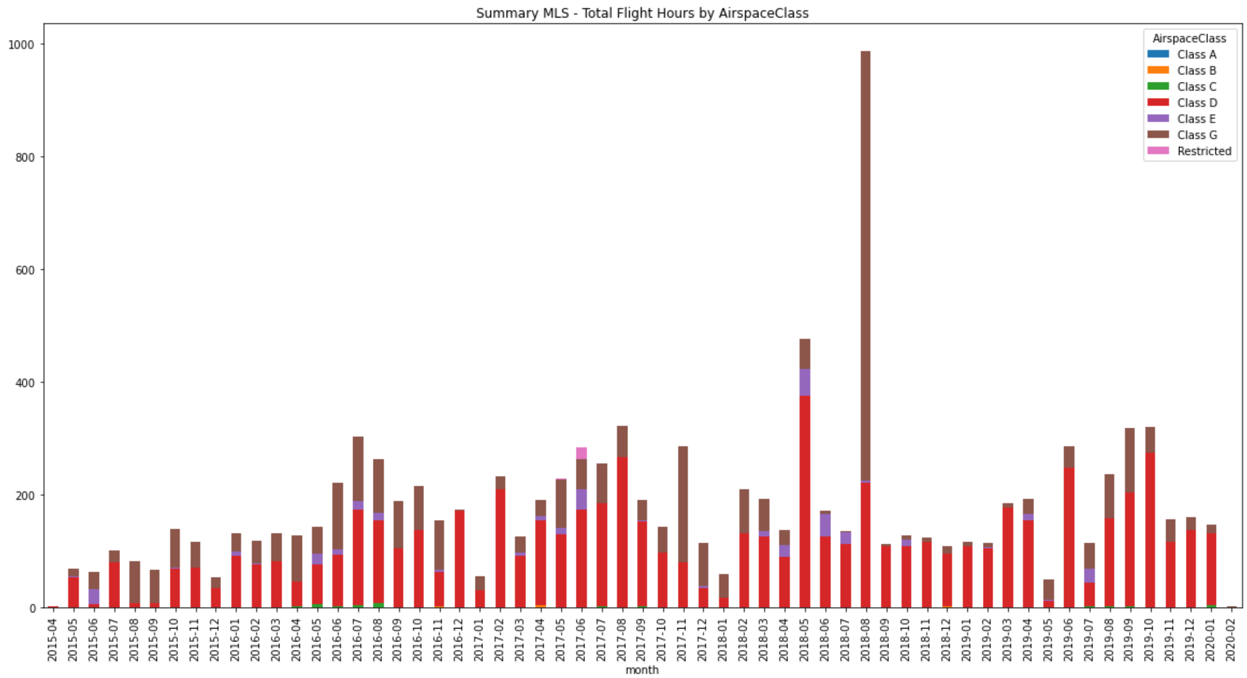


Figure 48. MLS total flight hours by weight categories

Figure 49 indicates that the summary MLS-total flight hours by Airspace Class fluctuated from month-to-month between 2015 and 2020. The graph surged in August 2018 with the highest value of approximate 1000 associated with class G.



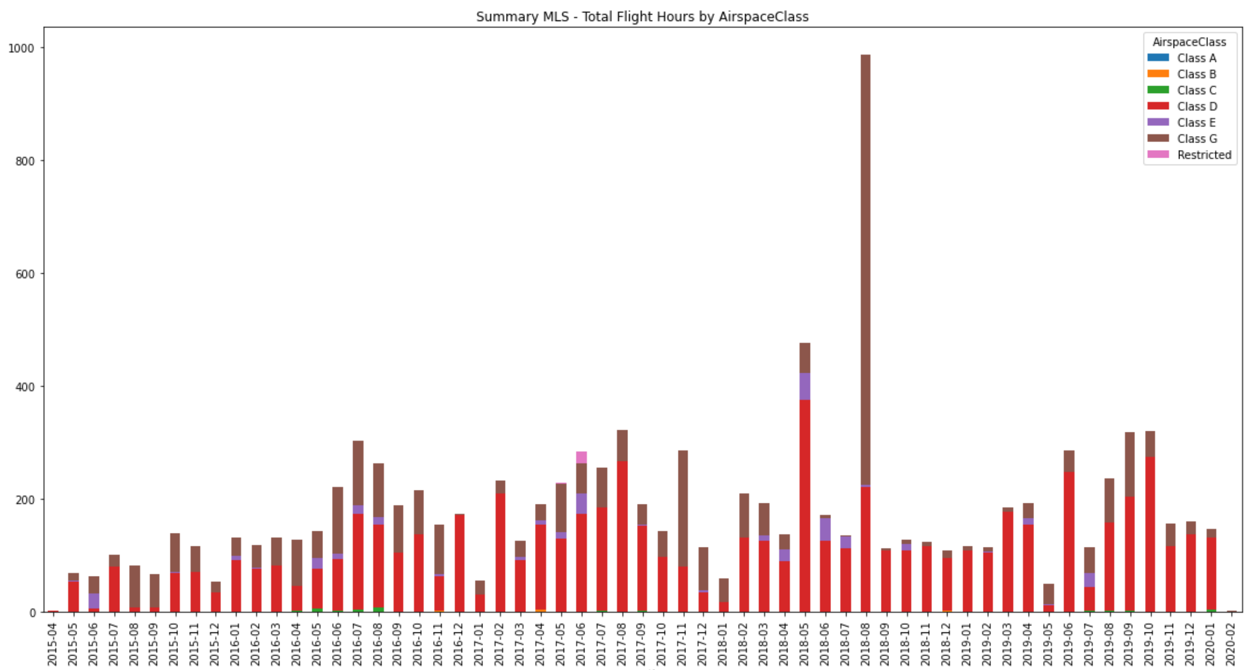


Figure 49. MLS total flight hours by airspace class.

6.4.3.2 UAS Test Site Incidents and Accidents

This section reports the descriptive statistics of MLS incidents and accidents at those test sites in Figure 50 to Figure 53.The bar chart in Figure 50 shows that the state of Nevada (NV) has the highest number of MLS incidents/accidents (9) by the operator from 2015 to 2019, followed by VA (6), ND (5), AK (3), and NM

(3). Additionally, Figure 51 illustrates the number of MLS incidents/accidents by event type from 2015 to 2019. The result shows that the unusual equipment malfunctions had the highest number of incidents/accidents (24), followed by accident (21), lost control link events (8), and aircraft collisions (1). Next, Figure 52 depicts the number of MLS incidents/accidents by the flight phase from 2015 to 2019. The result shows that the Takeoff phase had the highest number of MLS incidents/accidents (12), followed by Maneuvering MNV (10), En Route ENR (7), Landing LDG (7), Approach APR (3), and Uncontrolled Descent UND (2). Finally, Figure 53 shows the number of MLS incidents/accidents by airspace class from 2015 to 2019. The result indicates that class G has the highest number of incidents/accidents (28), followed by class D (17), class E 37), and class B (1). It should be noted that out of total of 16,770 operations, only 55 incidents or accidents were reported from May 2015 to June 2019. There may be more actual incidents that were not reported. The results only capture the reported incidents or accidents.

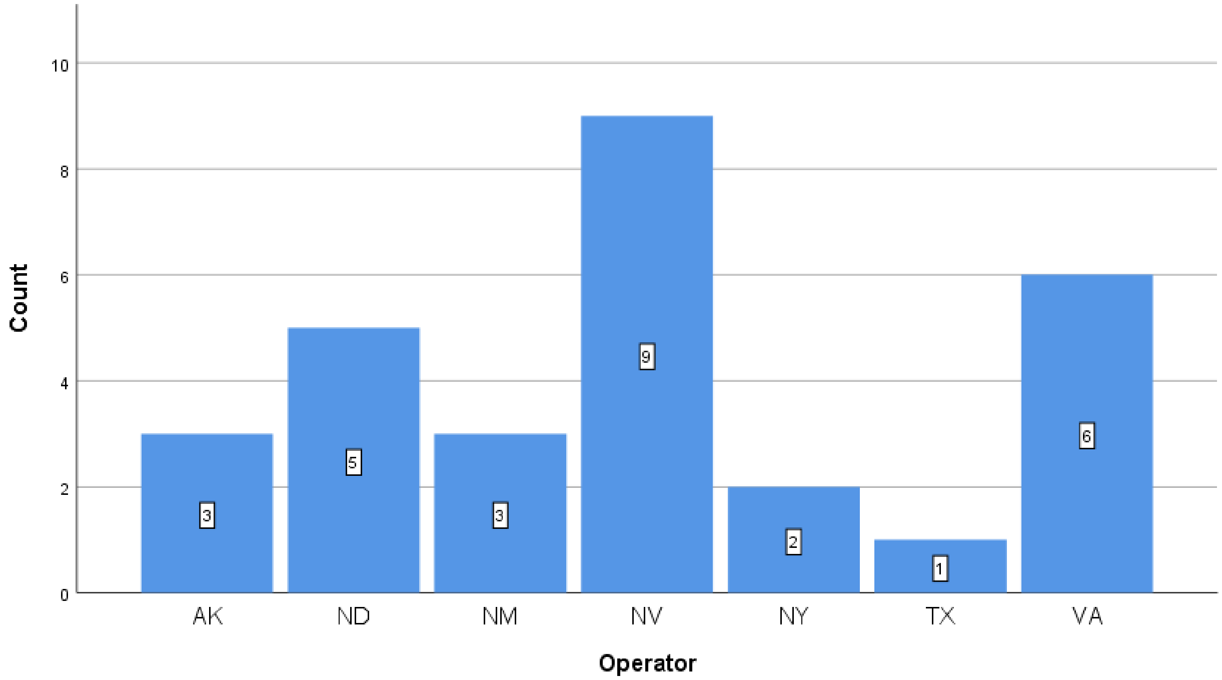


Figure 50. MLS incidents by operator.

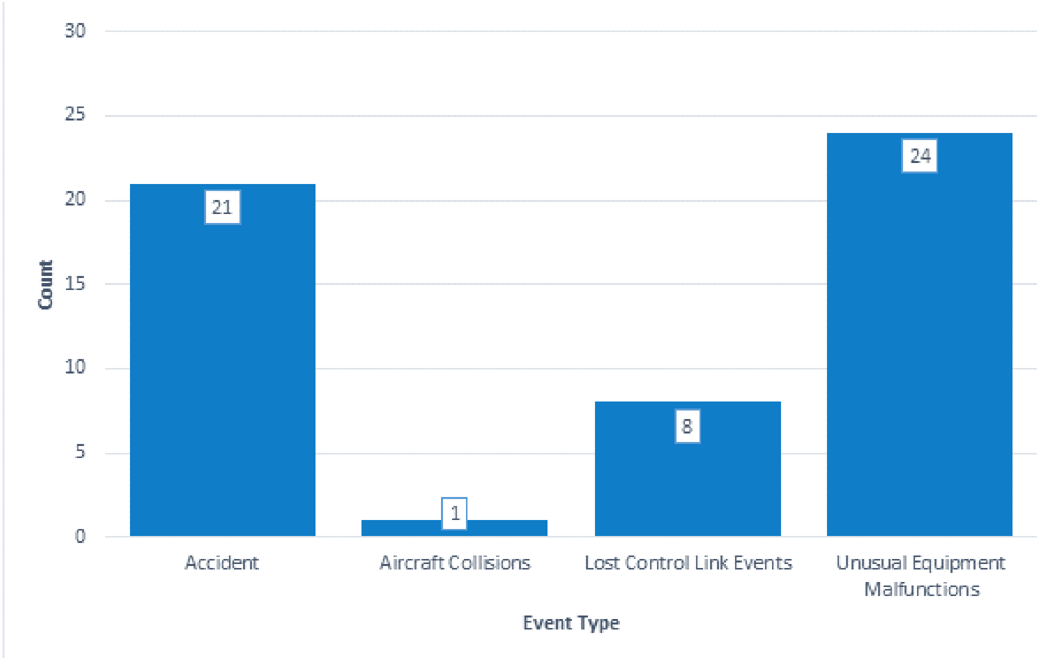


Figure 51. MLS incidents by event type.

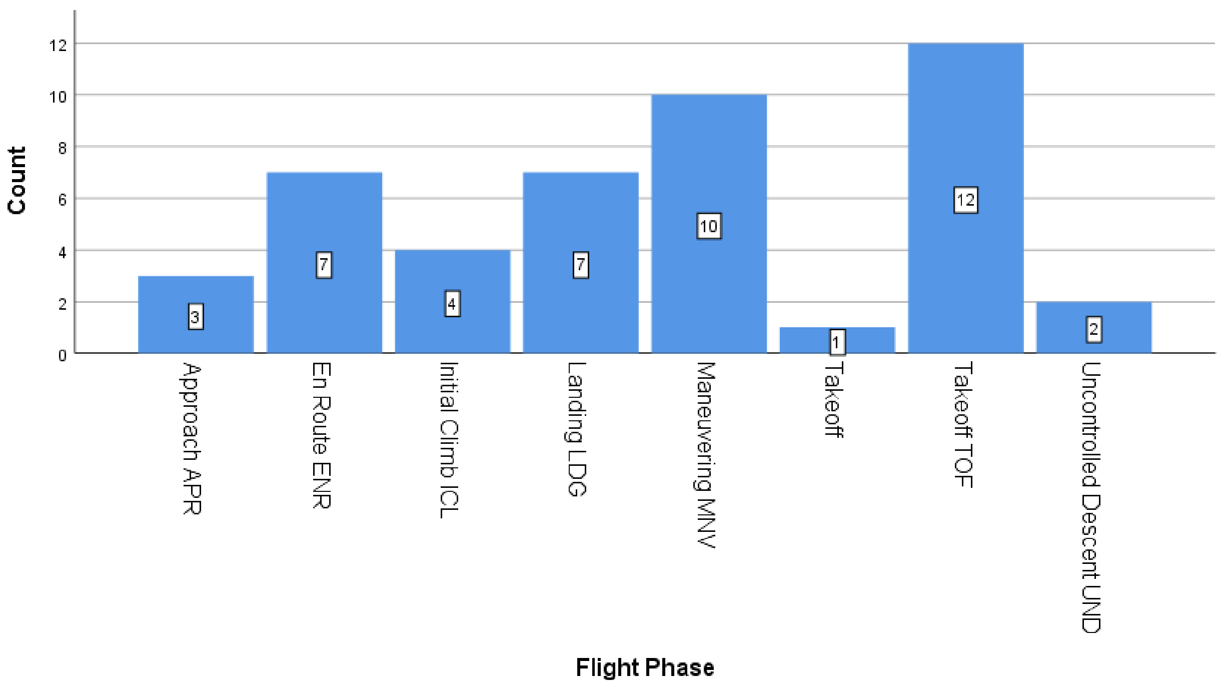


Figure 52. MLS operations by flight phase.

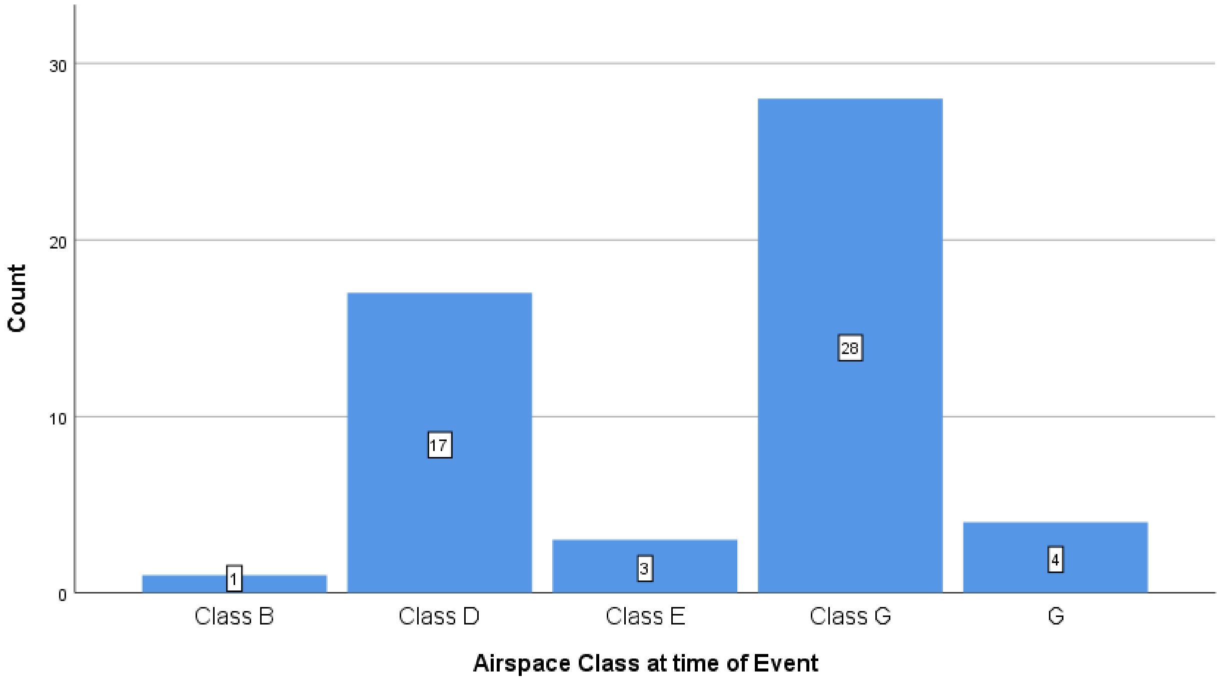


Figure 53. MLS operations by airspace class.

6.4.4 UAS Sightings Data

As the use of UAS is rapidly increasing, the information on UAS sightings reported by pilots, air traffic controllers, military personnel, and civilians has been collected and released by the FAA to proactively address the challenges of UAS integration into the NAS. This section analyzed sighting incidents across various regions and climate zones and projected future sighting incidents within the next twelve months.

6.4.4.1 Method of analysis

A word cloud was constructed to detect the most frequent words from sighting reports since the summary narratives are the primary part of the report. The word cloud is an exploratory method to detect any unusual terms or themes from the qualitative data. Then, trend analysis used descriptive statistics and visualization to capture the pattern of sighting incidents over time and the number of reports by states and climate regions. The local time of day when the incidents were reported was also analyzed to examine the times that most incidents occurred. Since the data is seasonal, it was decided to break down the reports into nine climate regions defined by NOAA: West, South West, South, South East, North East, Central, East North Central, West North Central, and North West[5]. By examining the sighting reports in each region, especially with regard to the time of day for incident occurrence, it is possible to observe any relationships between potential climate/weather conditions and the number of sighting incidents.

Finally, the time-series forecast method was used to predict future trends of sighting incidents from April 2020 to March 2021. More specifically, the ARIMA (Autoregressive Integrated Moving Average) method was used to construct forecasting models for future sighting incidents. It is a robust time-series forecast method that predicts future values based on the dependent relationship between an observation and number of lagged observations, differencing of raw observation and dependency between an observation and a residual error from a moving average model. There are three major parameters in the ARIMA model: p, d, and q. The attribute p is autoregressive order, d is differencing order, and q is moving average order. Finding appropriate parameters is key to this method, and it requires an iterative process, which includes trials and errors to fine-tune these values. First, autocorrelation analysis was conducted to examine autocorrelations for all lags, based on which a value of p can be decided. Then, values of d and q were determined through an iterative process of trials and errors until a satisfactory model fit and forecast accuracy was achieved. Residual autocorrelation function charts were examined to ensure only white noise exists. Model fit statistics include R^2 and Ljung-Box Q statistic test. R^2 of 0.5 or higher is generally considered acceptable (Hair et al., 2020). In addition, a non-significant Ljung test indicates there is no evidence of lacking model fit. In other words, the residuals are merely white noise (Box et al., 2016). Ten ARIMA models were constructed using national data and data from each of the nine climate regions .

6.4.4.2 Sighting incident analysis results

6.4.4.2.1 <u>Trend analysis</u>

The word cloud representing the most frequent words from the reports is presented in Figure 54. The results show that the most frequent words include “drone”, “reported”, “pilot”, “notified”, “feet”, and “evasive.” This finding is expected given the nature of sighting reports. The words “B737” and “C172” also showed up in the word cloud, indicating encounters between UAS and commercial airplanes and GA aircraft. This analysis suggests incidents occurred near airports or on the final approach and aircraft had to take evasive action.

[5] https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php

Figure 54. Word cloud of sighting incidents.

Other words in the word cloud do not provide any further insights of the sighting incidents. This finding is consistent with the findings by GAO (2019), which indicates the level of noise in the UAS sighting data. The narratives in the sighting data are somewhat unstandardized, and the spotters were asked to report the incidents freely without well-structured reporting forms. The data also contain false alarm incidents and incidents with many missing values (Truong and Choi, 2020). Accordingly, further trend analysis and time-series forecast were conducted to capture the patterns of the sighting incidents and future trends.

Figure 55 shows the trend of sighting reports over time at the national level. It is worth noting that the overall number of incidents have increased from 2015 to 2019, with a peak of about 300 reports per month in June 2018, followed by 250 reports in June 2019. The trend is seasonal, with a lower number of reports in the wintertime and a much higher number of reports in the summertime. This finding is expected since there are more UAS operations in the summer than the winter A more in-depth look at different climate regions in subsequent data analyses could give us more insight into the sighting incidents by weather.

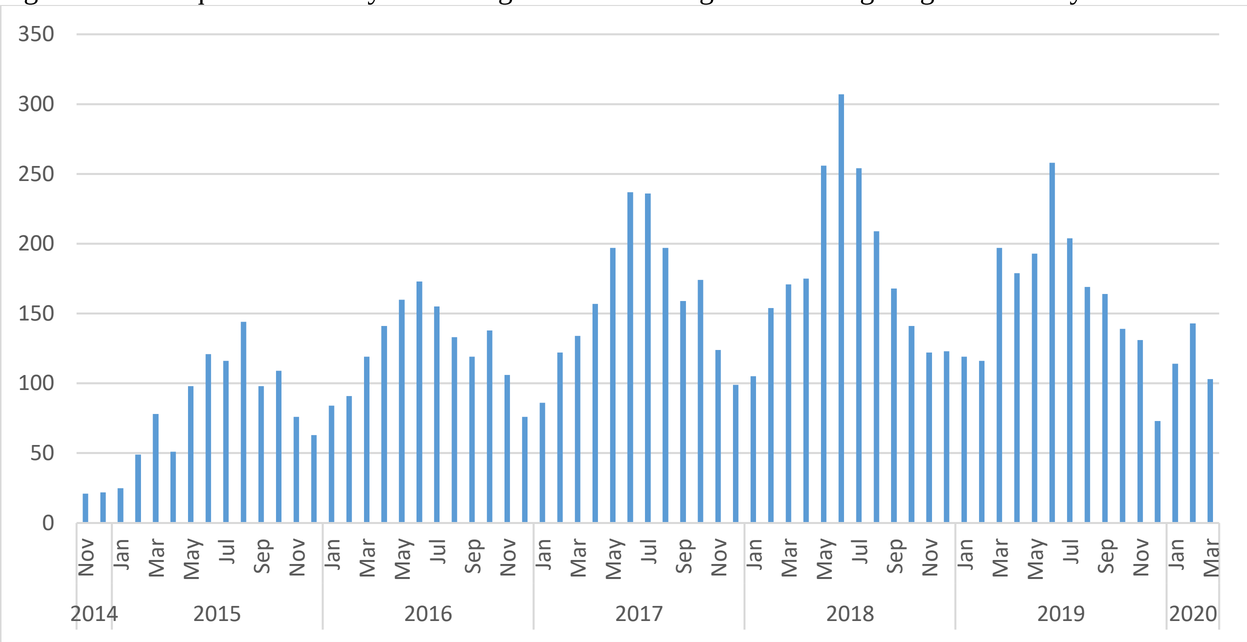


Figure 55. National sighting incidents over time.

The map visualization in Figure 56 provides an overview of all UAS sighting incidents by states. California, highlighted by a yellow color, had the highest number of sighting incidents, in a range of over 700 incidents, followed by Florida, Texas, and New York, in a range of 400 incidents. This finding is consistent with the previous findings with respect to UAS registrations. Those states are also the states with the highest UAS registrations, which explains the high number of sighting incidents occurring there.

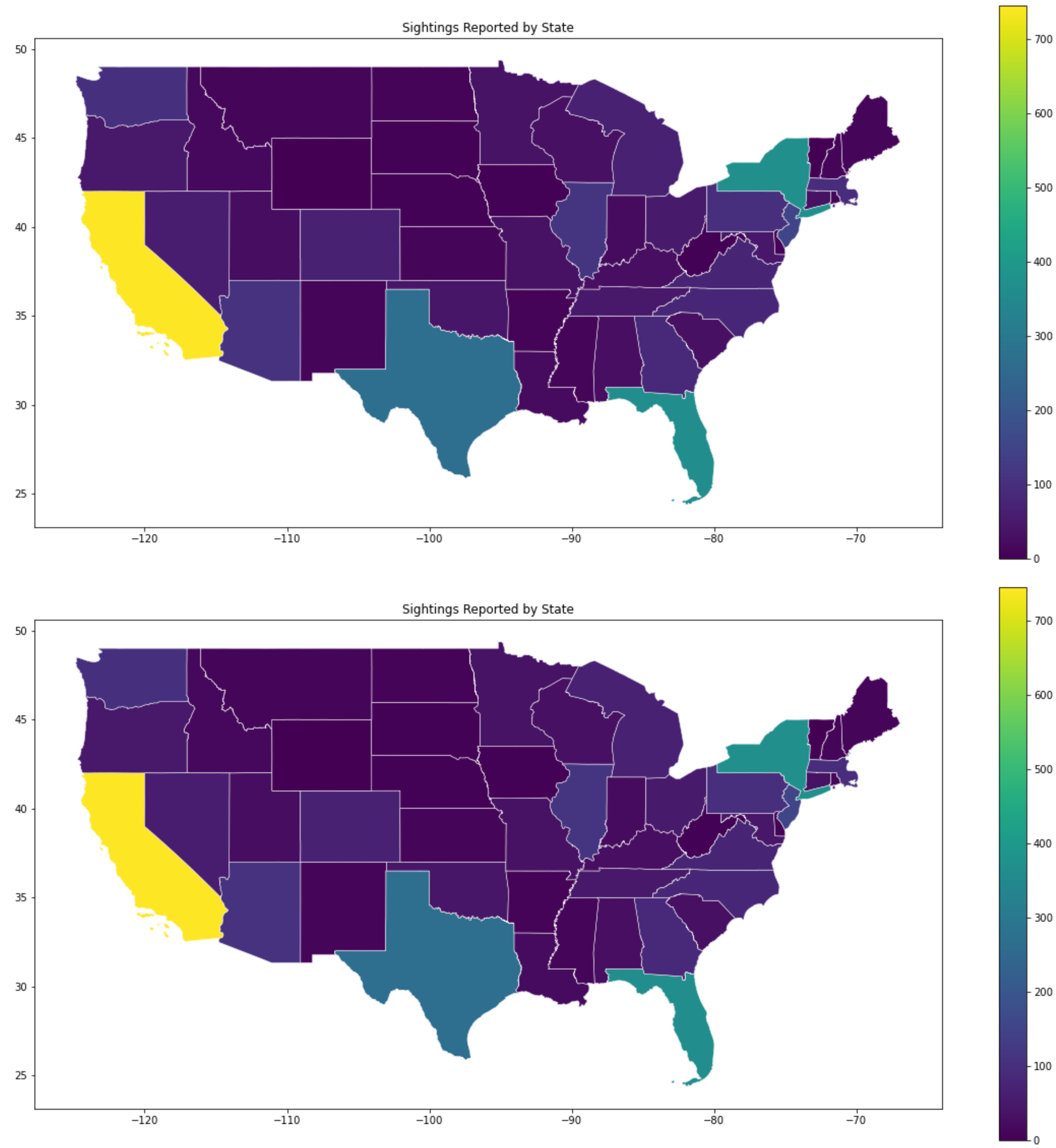


Figure 56. Sighting incidents by states.

The sighting incident data can also be mapped by county as depicted in Figure 57. The figure matches expectations given the mapping by state and continues to show that sightings occur in more populated areas. The sightings data was re-plotted by county to measure the sightings per capita. Figure 58 presents the results, which do not yield any clear trends as the number of sighting reports remain quote low throughout the country.

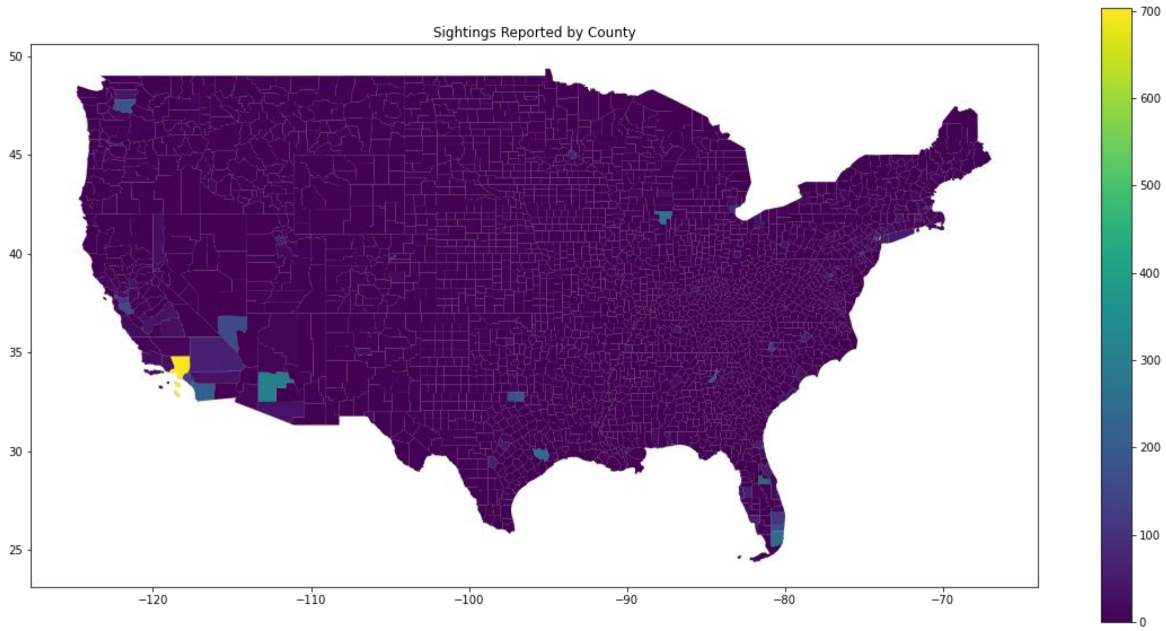


Figure 57. Number of Sighting Reports by County.

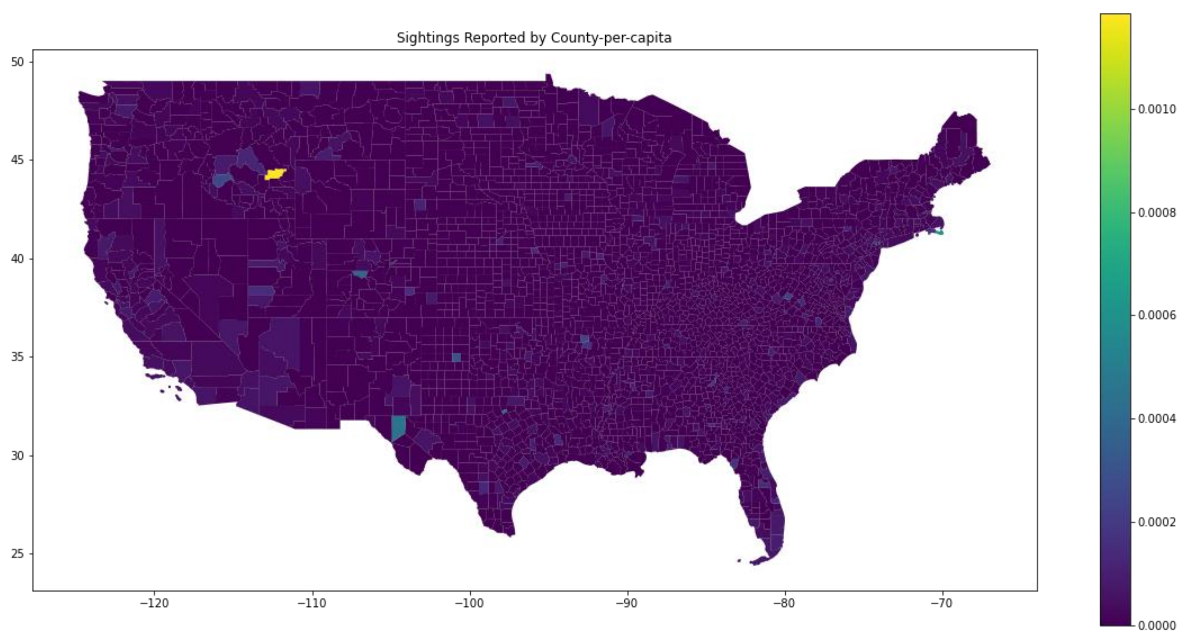


Figure 58: Per Capita Sightings Reports by County.

6.4.4.2.2 Sighting reports by local time of day and climate regions

This section focuses on the examination of relationship between time of day and the occurrence of reported sighting incidents. The results are presented both at the national level and in nine different climate regions to identify any potential relationship between weather and sighting incidents. The project uses nine climatically consistent regions as recommended by NOAA, including West, Southwest, South, Southeast, Northeast, Central, East North Central, West North Central, and Northwest (Figure 59). Figure 60 shows the percent of sighting incidents across these regions. The highest percentage of sighting incidents were reported in the Southeast, Northeast, South, and West regions. Those are the regions with larger populations and relatively warmer weather, except for Northeast, which has a large population. The regions with the lowest sighting incidents are Northwest, East North Central, and West North Central. Those are the regions with colder weather and smaller populations.

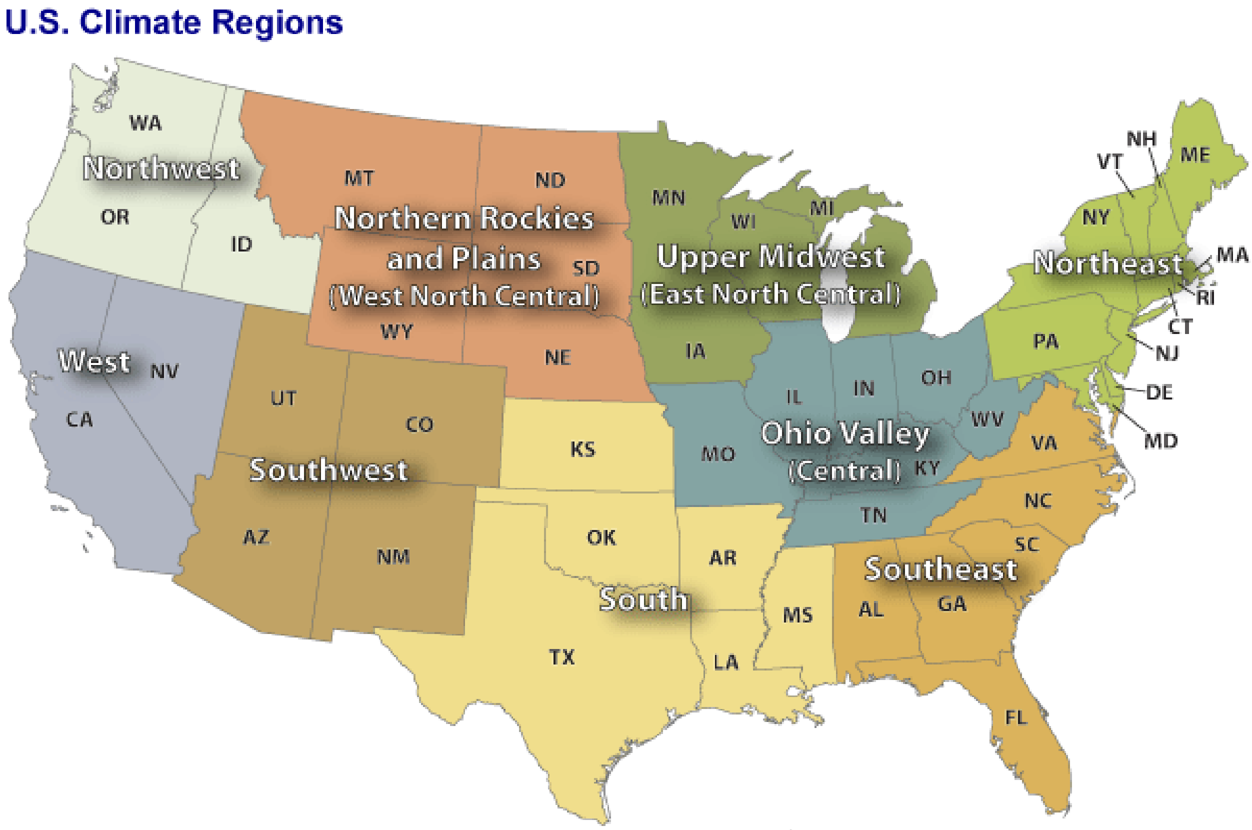


Figure 59. NOAA nine climate regions.[6]

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[6] Source: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php

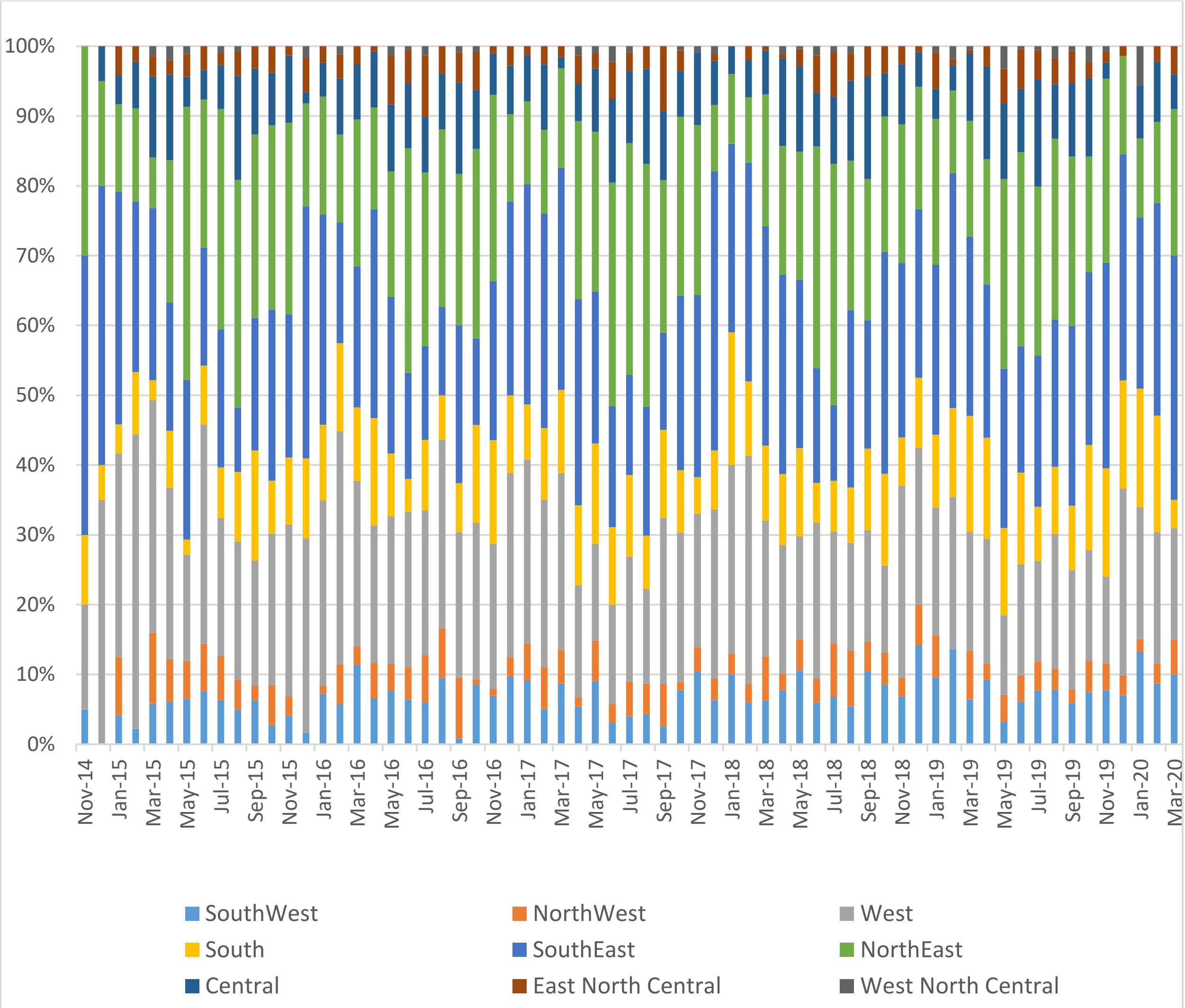


Figure 60. Number of sighting incidents by climate region.

The visualizations depicted from Figure 61 to Figure 70 show the UAS sighting reports by local time of day from November 2014 to March 2020 for the whole nation or by nine climate regions. The national chart shows that most incidents occurred between 9:00 am and 9:00 pm when it is bright enough for the visual line of sight. There were much fewer incidents between midnight and the early morning. In addition, there were more incidents in the summer than in the winter.

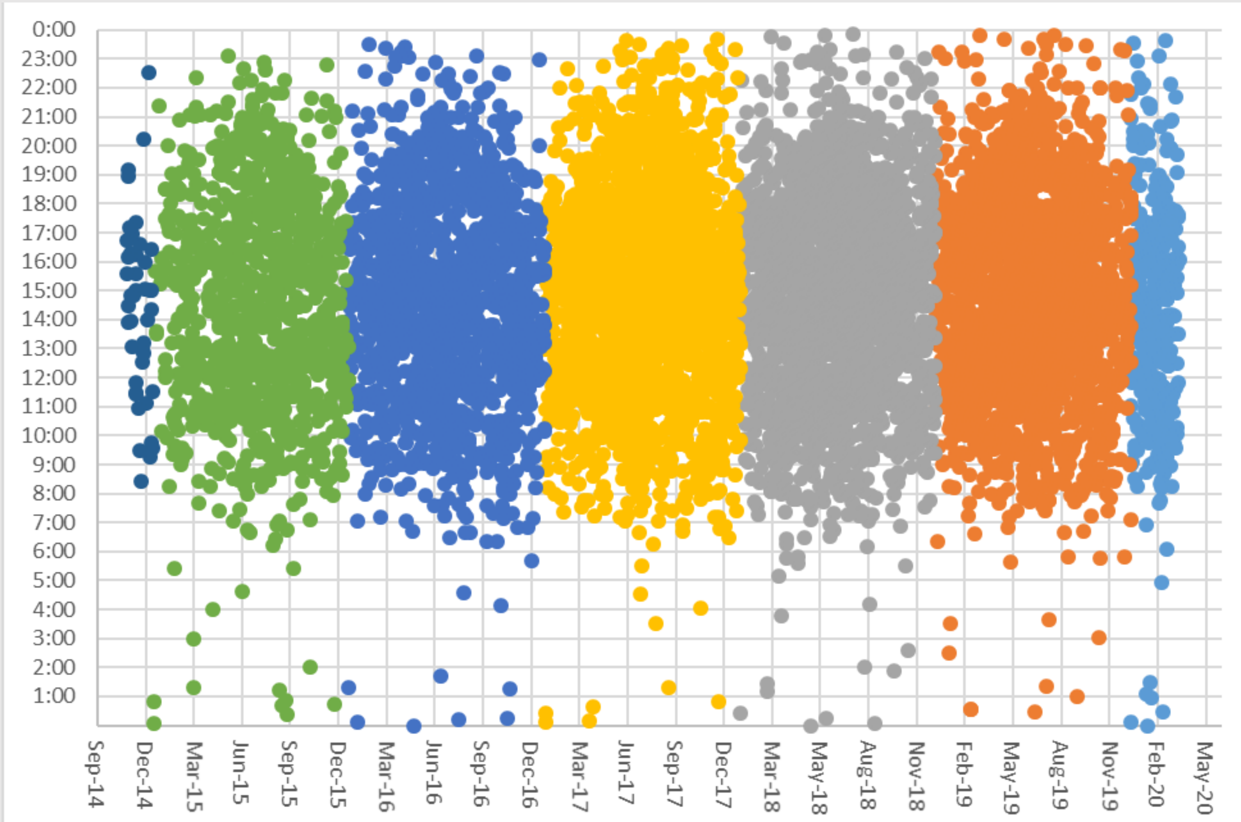


Figure 61. UAS Sighting Reports by Local Time of Day – National.

At the regional level, the regions with larger populations and warmer weather, including West, South, and Southeast, show more density in the sighting incidents by time of day. It can be seen that there were a lot of activities in the winter compared to other regions. The incidents seemed to occur consistently between 9:00 am and 9:00 pm throughout the year since there is enough daylight for UAS operations. Northeast has relatively cold weather but large populations. That is why this region is also among the regions with the most incidents. However, we noticed many fewer incidents in the winter, and while there were still a number of incidents, in the months from October to March, most incidents seemed to occur between 9:00 am and 6:00 pm.

Central and Southwest are the regions with medium populations but colder weather. We can see that most incidents occurred between 10:00 and 8:00 pm in the summer and spring, and there were many fewer incidents in the winter. The regions with the least incidents are Northwest, West North Central, and East North Central, which have extremely cold weather and small populations. In those regions, due to limited daylight time per day, we can notice most incidents occurring between 11:00 am and 6:00 pm in the summer and spring, and almost no activities in the winter, especially in West North Central.

In conclusion, weather and daylight time appear to be associated with higher numbers of sighting incidents. Additionally, the population size and population densities could also be factors. As shown in Figure 62 to Figure 70, relatively higher sightings in Southeast and Northeast may be the result of larger population densities and the location of airports nearby. Since many sightings were observed during take-offs and landings, the location of airports and nearby residential areas appear to have impacts on sighting incidents. In regions such as Northeast, Southeast, and West, there are large population densities and large airports located in close proximity. The same pattern has been observed with the UAS registrations previously. These regions, of course, have warmer weather and longer day times, which allow more flight operations and longer flight time. These patterns explain the high number of sighting incidentsincidents in those regions. On the other hand, in the Northwest, East North Central, and West North Central regions, the population densities are much lower, and there are also fewer large airports in close proximity. Additionally, the numbers of UAS registrations are lower in those regions. Finally, these regions have colder weather and shorter day times, which certainly limit the number of operations and flight time. These patterns may explain the low number of sighting incidents in those regions. Future research could focus on building a predictive model for UAS sighting incidents based on weather and daylight time variables.

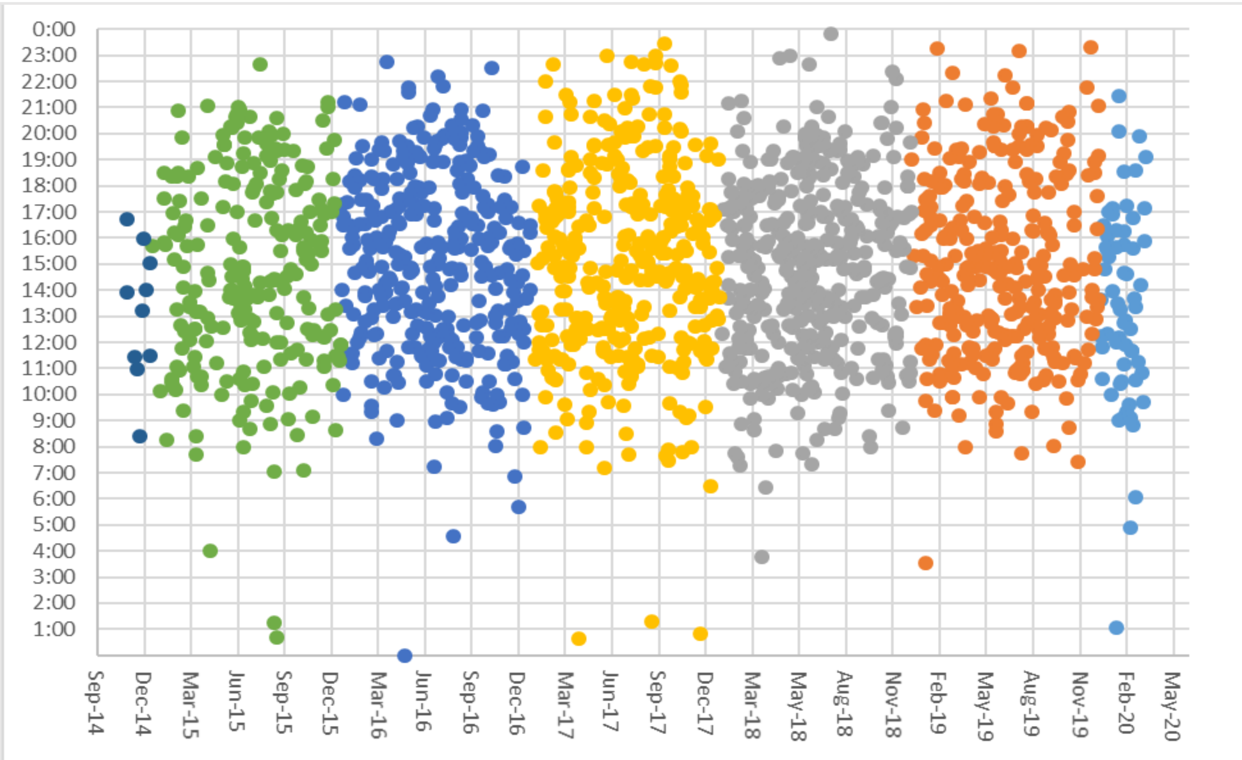


Figure 62. UAS Sighting Reports by Local Time of Day – West

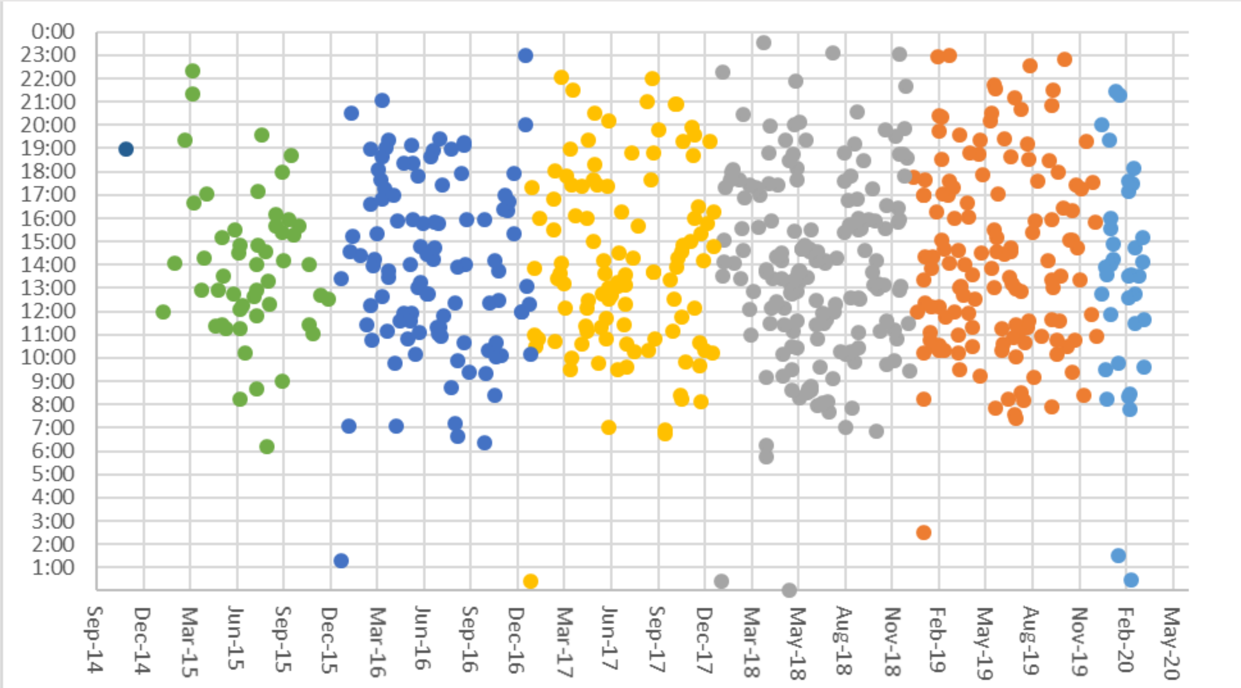


Figure 63. UAS Sighting Reports by Local Time of Day – Southwest.

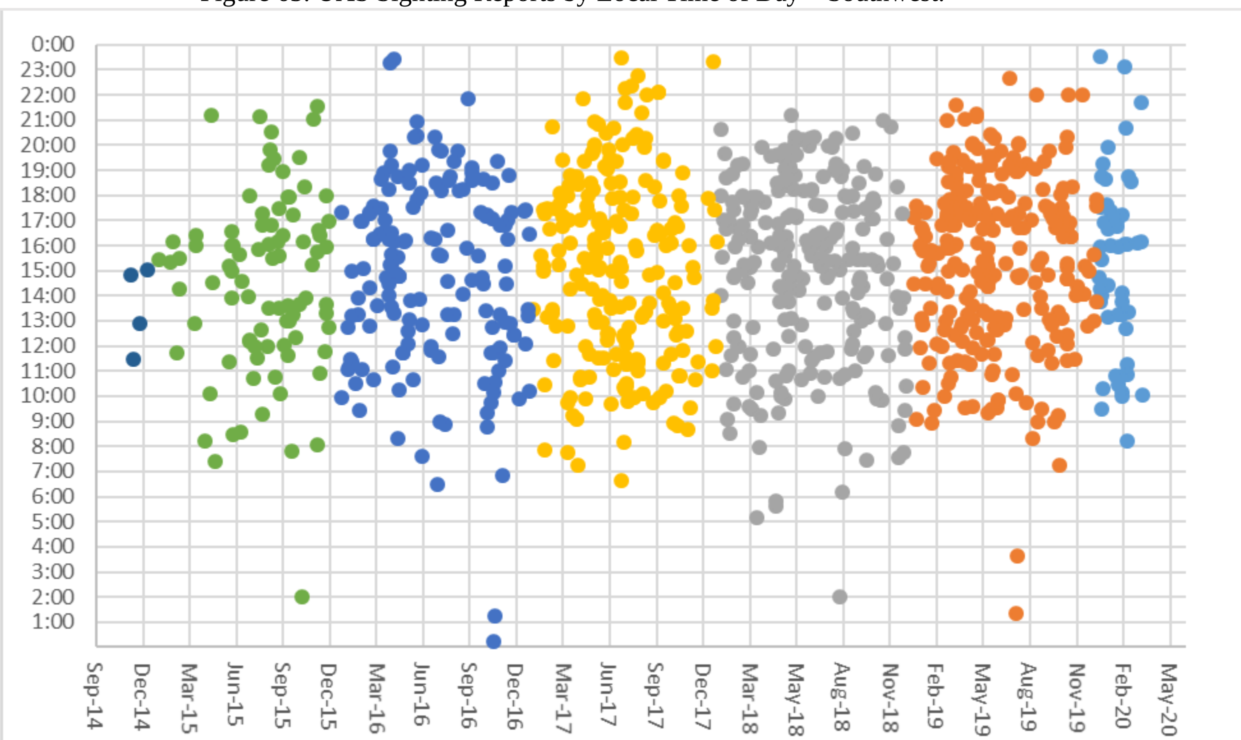


Figure 64. UAS Sighting Reports by Local Time of Day – South.

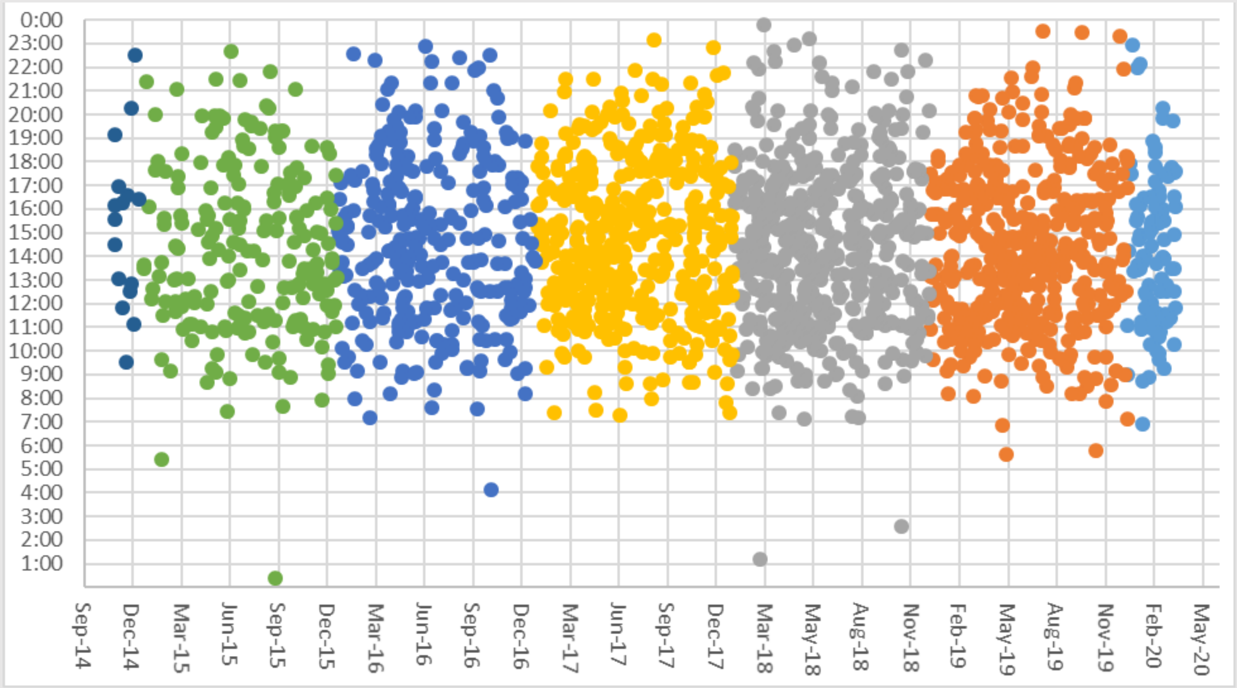


Figure 65. UAS Sighting Reports by Local Time of Day – Southeast.

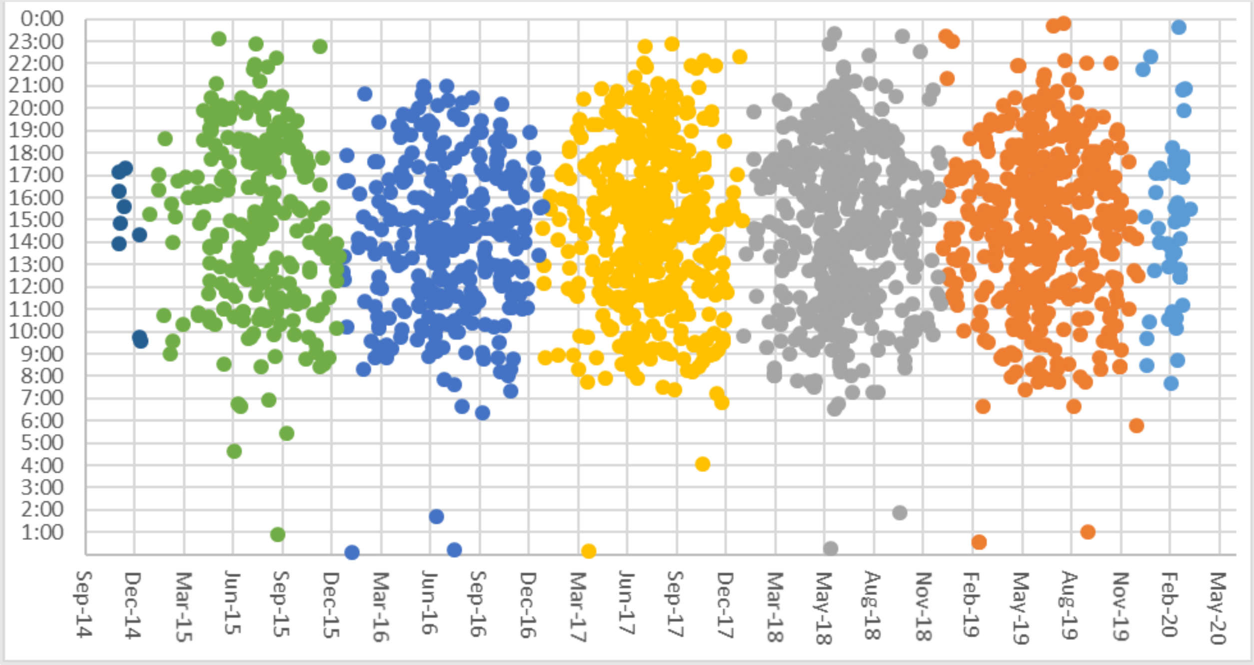


Figure 66. UAS Sight Reports by Local Time of Day – Northeast.

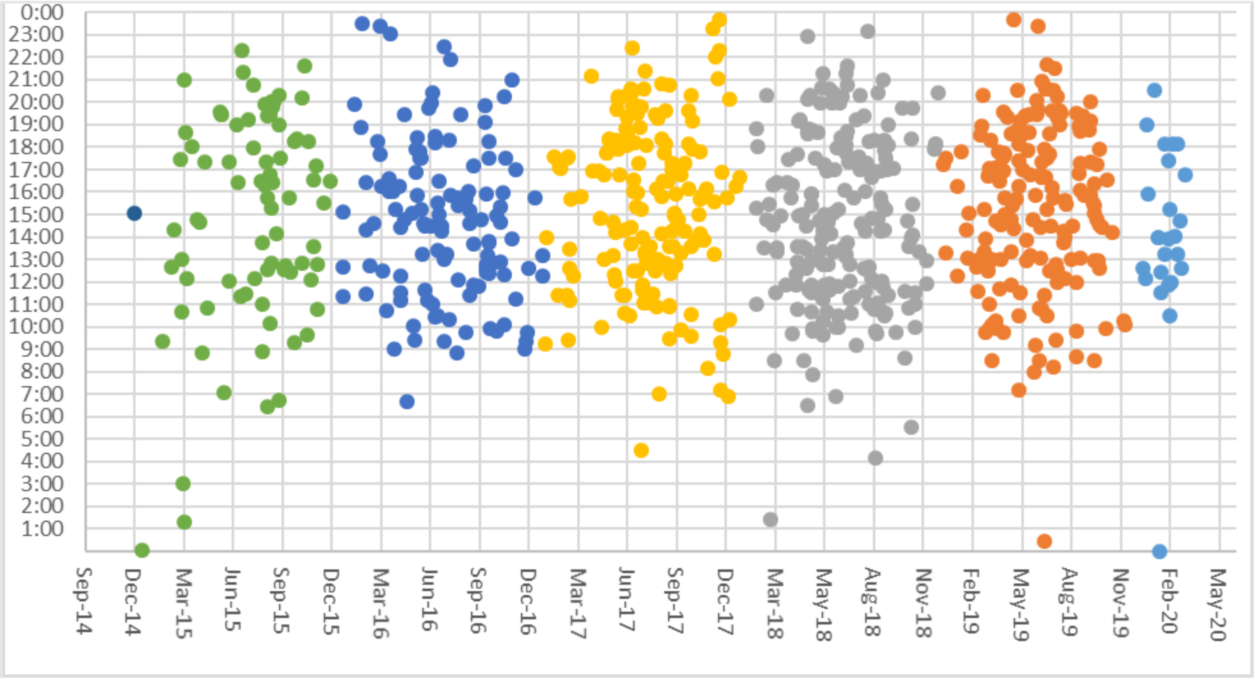


Figure 67. UAS Sighting Reports by Local Time of Day – Central.

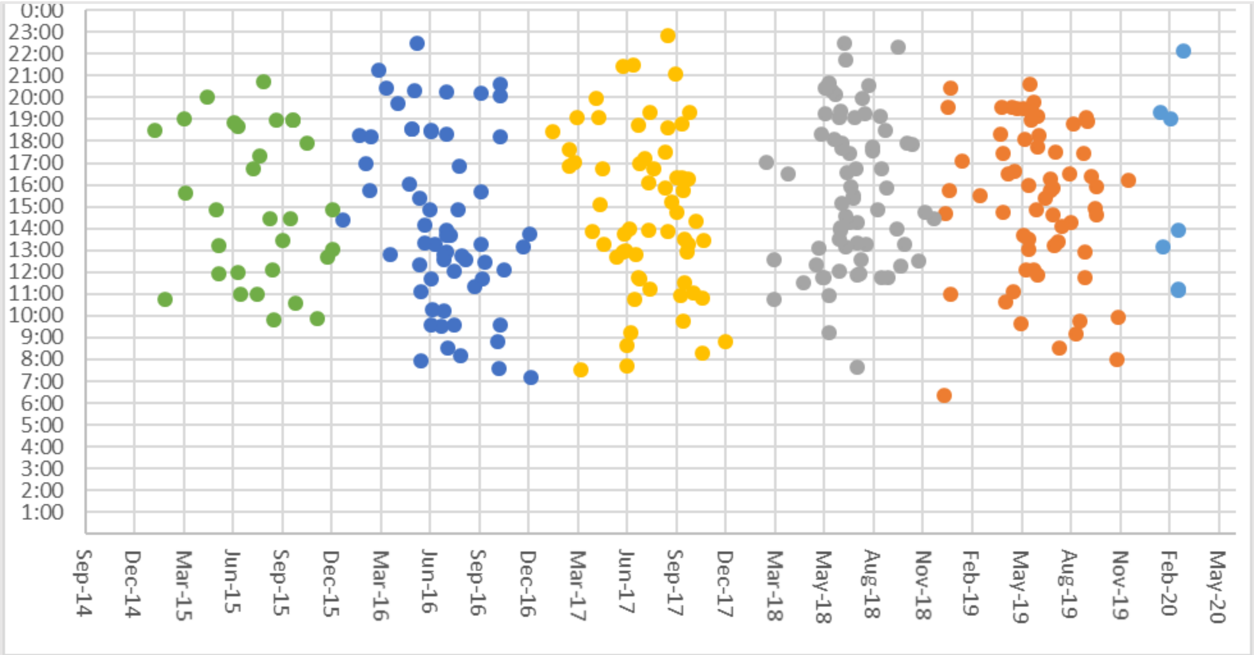


Figure 68: UAS Sighting Reports by Local Time of Day – East North Central.

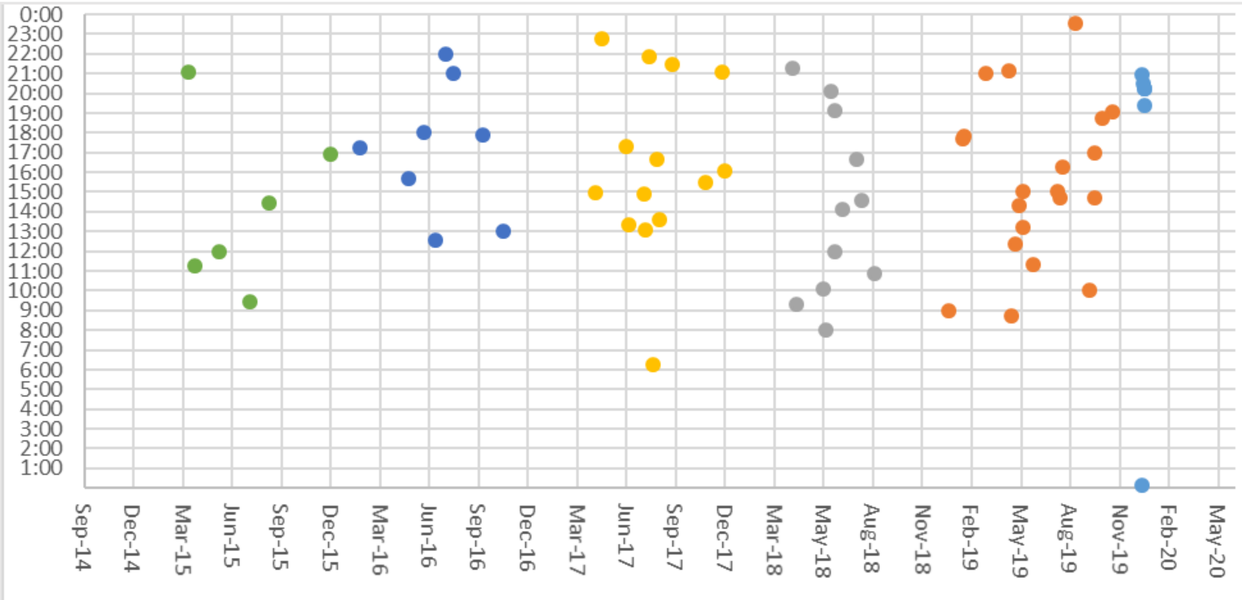


Figure 69: UAS Sighting Reports by Local Time of Day – West North Central.

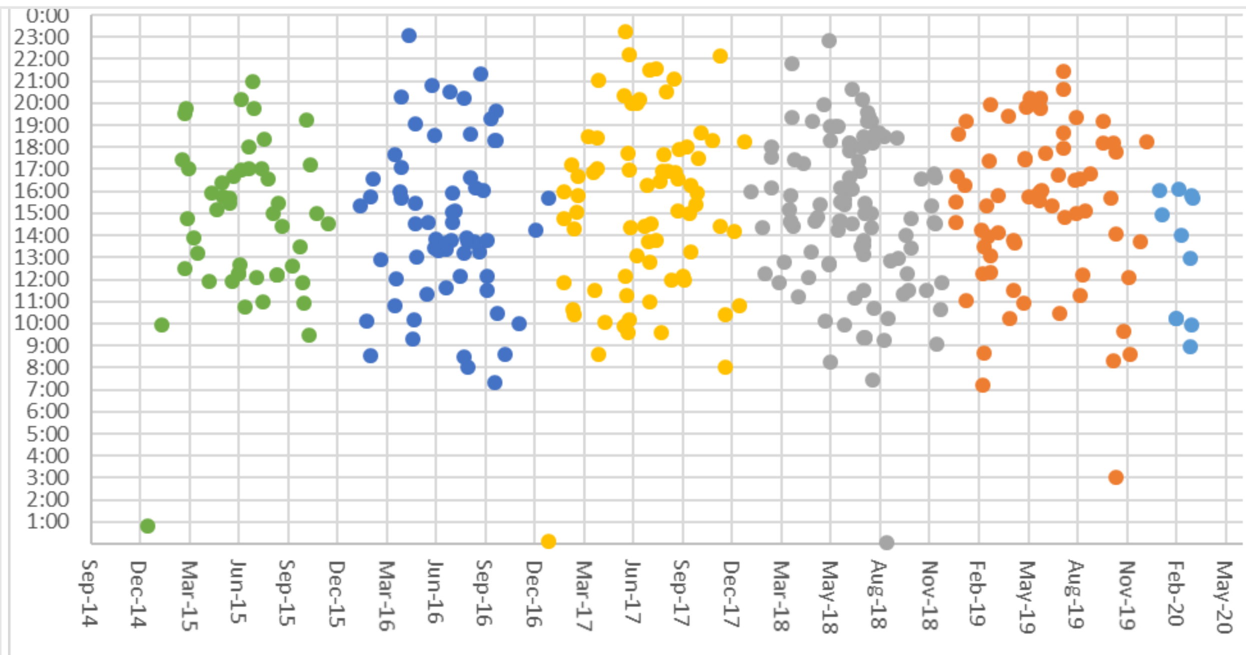


Figure 70: UAS Sighting Reports by Local Time of Day – Northwest.

6.4.4.2.3 Projection of future sighting reports by climate regions

ARIMA models were constructed for sighting incidents at the national level and in nine climate regions to project future trends of sighting reports. Ten ARIMA models are constructed with a 95% confidence interval. For each model, the autocorrelation analysis results are examined to determine the appropriate p-value for the model. Then, the iterative process is used to find the appropriate values for q and m to ensure the model fit. Table 16 presents the forecast results for ten ARIMA models, including the model configuration, and model fit based on R^2 and Ljung-Box Q statistics. Overall, all models achieved a good model fit with R^2 greater than 0.5. In addition, all models have non-significant Ljung-Box Q statistics, indicating that there is no evidence of lacking model fit. In other words, the residuals are mainly white noise.

Table 16. ARIMA models and statistical results.

Forecast Model	ARIMA	R^2	Ljung-Box Q statistics	Sig
National	10, 1, 1	0.765	10.911	0.143
West	16, 1,1	0.418	03.077	0.079
Southwest	15, 1, 1	0.55	3.296	0.192
South	12, 1, 1	0.624	4.454	0.486
Southeast	10, 1, 1	0.637	8.08	0.326
Northeast	11, 1, 1	0.728	12.22	0.06
Central	10, 1, 1	0.647	11.574	0.115
Northwest	11, 1, 1	0.5152	7.297	0.294
East North Central	11, 1, 1	0.539	8.421	0.209
West North Central	11, 1, 1	0.666	5.858	0.439

Figure 71 shows the forecast of future sighting incidents at the national level. The data is seasonal with peak numbers in the summer and lowest in the winter. The model projected that in the next twelve months, sighting reports would increase in the summer toward September 2020 and then start decreasing until January 2021, before they begin climbing again.

The forecasts in nine climate regions are shown in Figure 72 to Figure 80. The charts indicate that sighting incidents in these regions are also seasonal as the national data, but with much more fluctuation than the national data. In regions such as West, Southwest, Southeast, Northeast, and Northwest, sighting incidents peaked in June 2018. The other regions seem to have more stable seasonal trends. It is important to note that regions, such as East North Central and West North Central, have very low sighting incidents, with zero reports in several months, which could lead to the high fluctuation in the pattern.

As for the future 12-month forecast, it seems that most regions will experience some fluctuation in sighting reports in the next twelve months. In most cases, the number will increase toward the summer of 2020 and then decrease in the winter, before rising again in early 2021. However, this pattern is only true for regions such as Southeast, Northeast, Central, Southwest, East, North Central, and Northwest. Other regions, including West North Central, South, and West, will experience much more fluctuation in the near future. Interestingly, in the case of the West region, the sighting incidents will seem to decrease gradually in the next twelve months. It is important to note that time-series forecast is based on the temporal dependence of the data, in other words, the relationship between values at two different data points of the same target variable. Effects of other factors are not included in those models: (a) isolation/reduction of "noise" in the data when remote ID and/or other technologies becomes available; (b) detection technologies are in place monitoring Class D and Class B airspaces, in particular; and (c) other NPRMs become rule, e.g., external markings. Effects of these factors should be further investigated in future research by consolidating the sighting reports with other data sets.

Overall, the effect of weather is not apparent in the pattern of sighting incidents, especially in the forecast numbers. Nonetheless, we notice some differences across those nine regions in terms of the seasonal trend and future trends. Further research should focus on examining how demographics, population densities, number of large airports, weather conditions, and daylight time in those regions would contribute to the changes in UAS sighting reports.

Those graphs also show the 95% upper and lower bounds of the forecast models; in other words, we are 95% certain the actual data falls between those upper and lower bounds. It appears that the national model has a more accurate forecast than regional models. As shown in those figures, there are more noises in the sighting incident data at the regional level, especially the regions with fewer sighting reports, such as Southwest, East North Central, West North Central, and Northwest. While those are mainly white noises, as stated above, they do affect the 95% upper and lower bounds of those models.

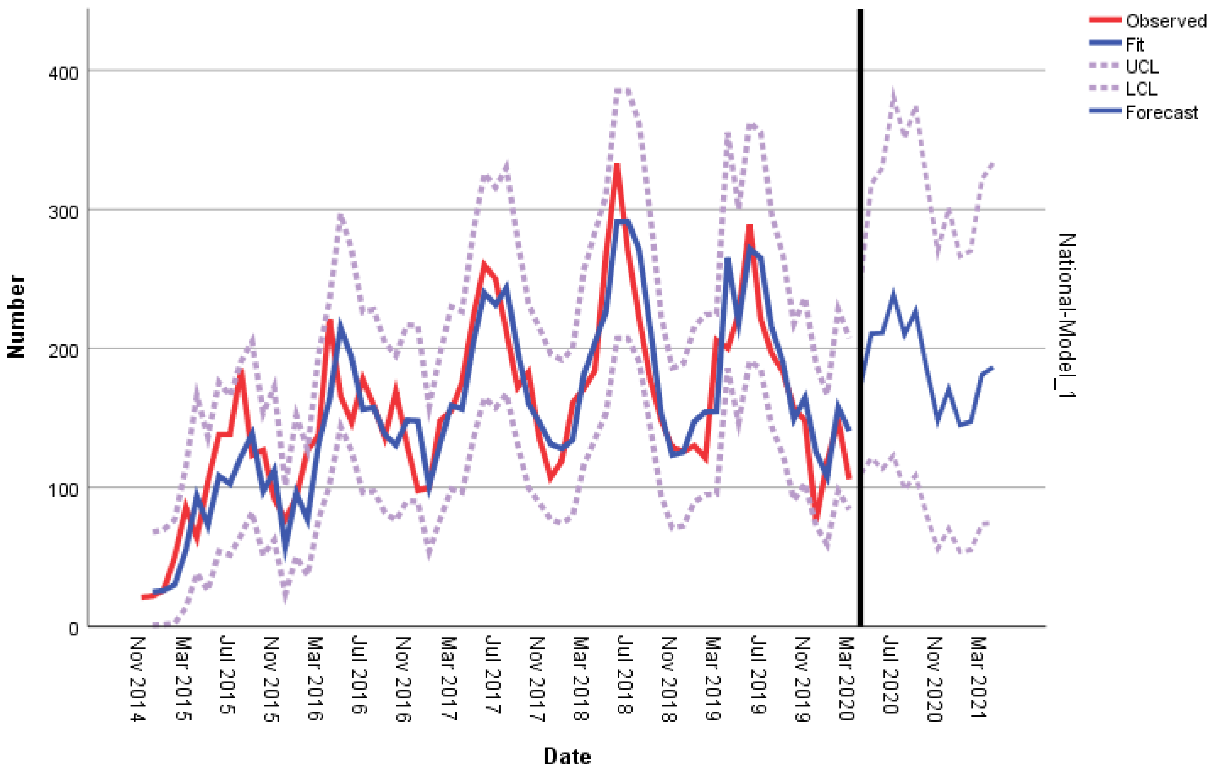


Figure 71. Sighting Incidents 12-Month Forecast – National.

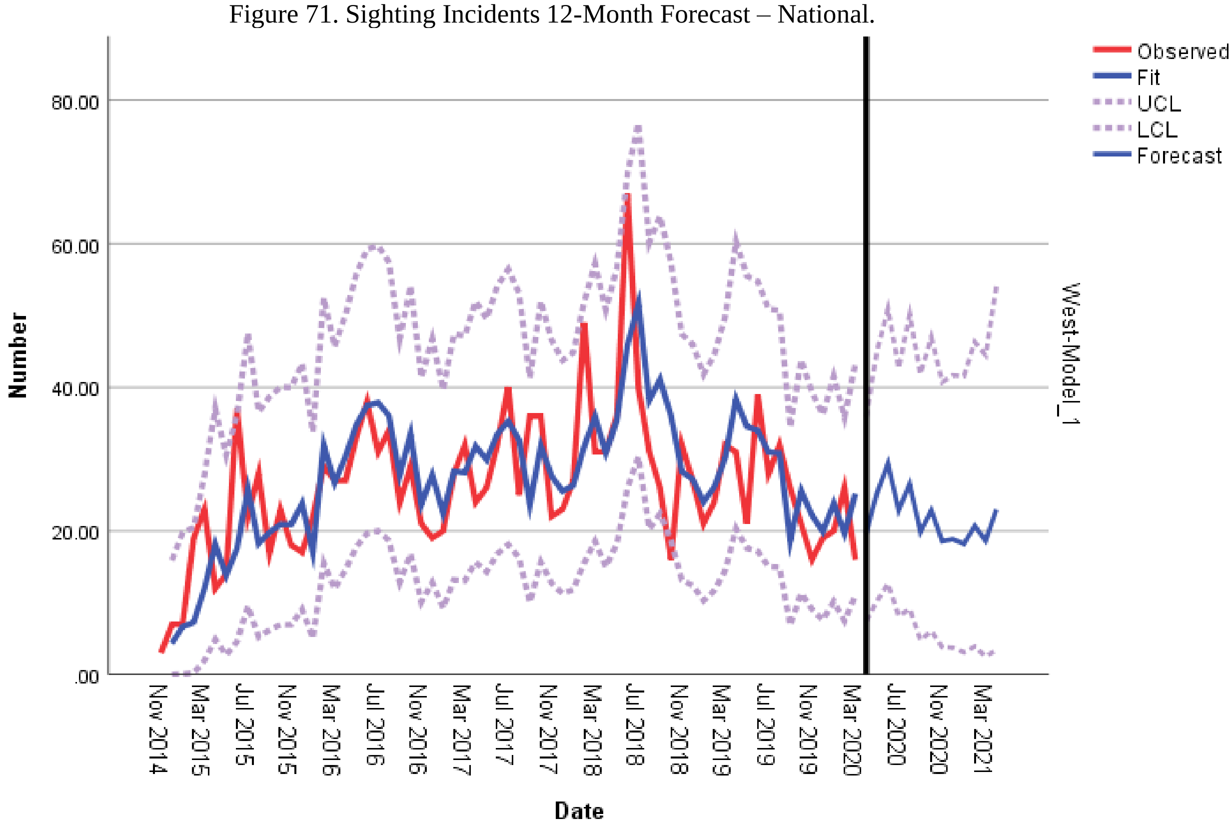


Figure 72. Sighting Incidents 12-Month Forecast – West.

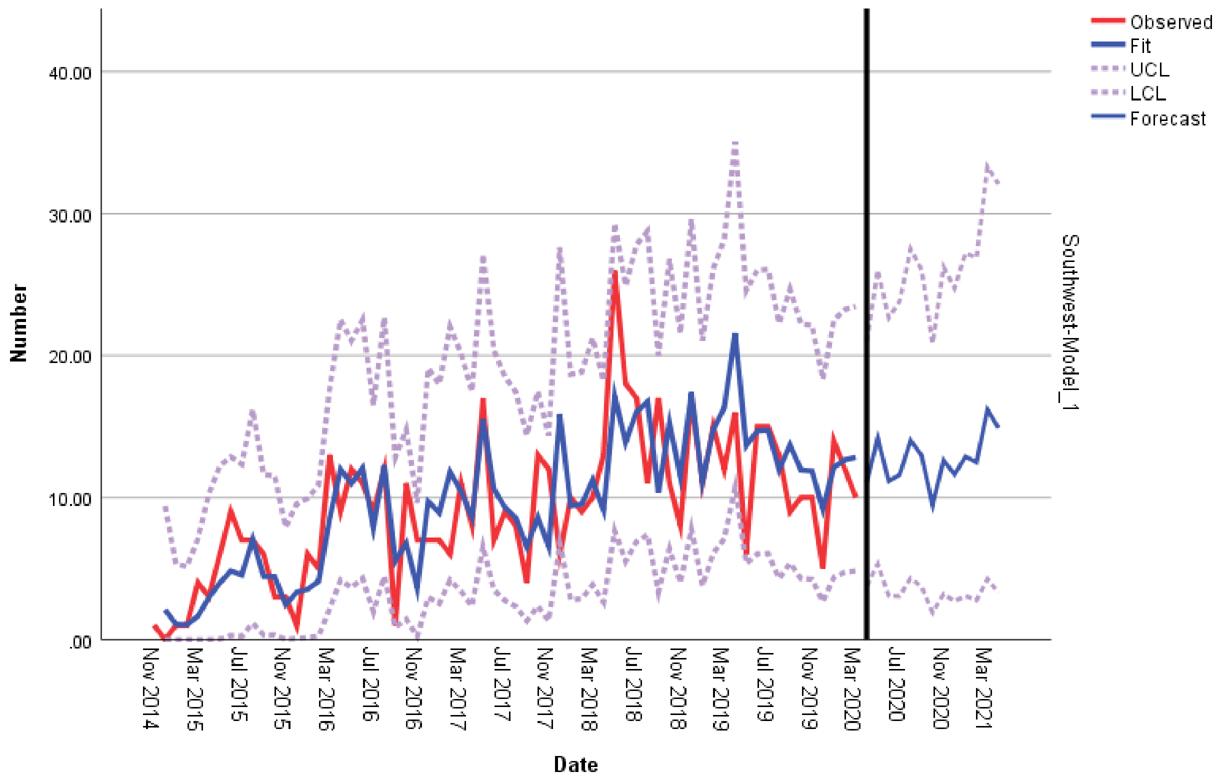


Figure 73. Sighting Incidents 12-Month Forecast – Southwest.

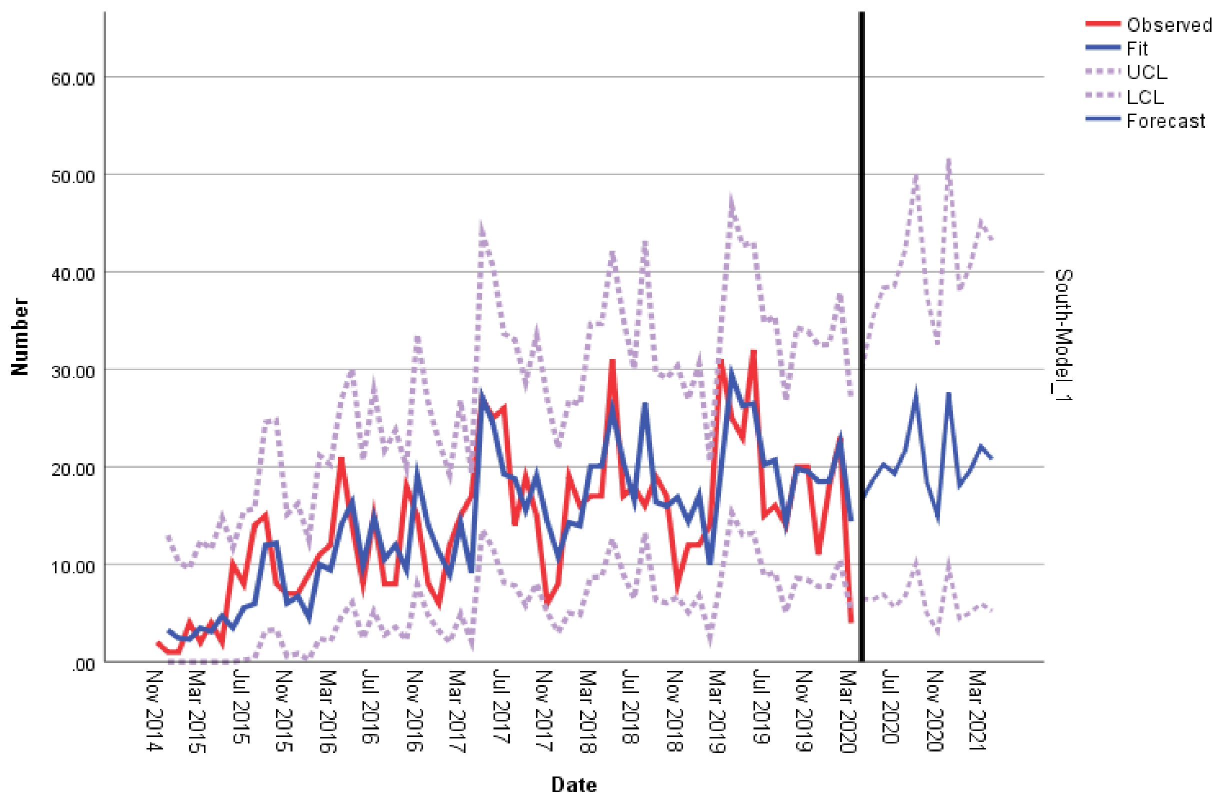


Figure 74. Sighting Incidents 12-Month Forecast – South.

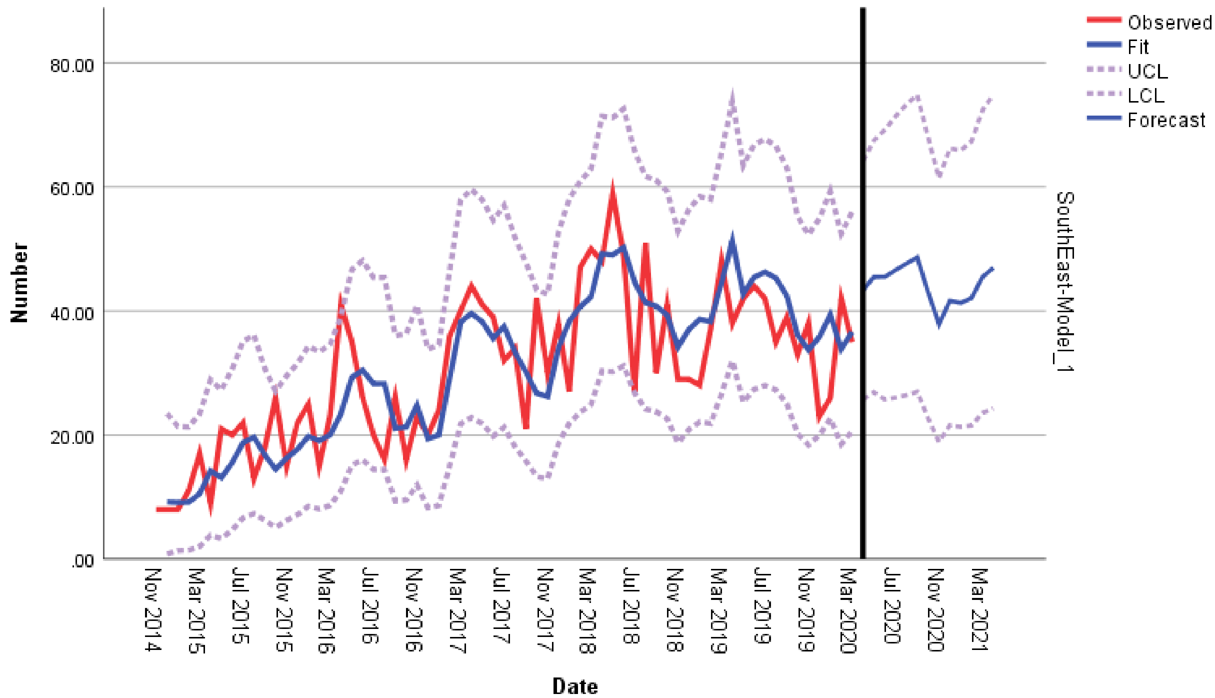


Figure 75. Sighting Incidents 12-Month Forecast – Southeast

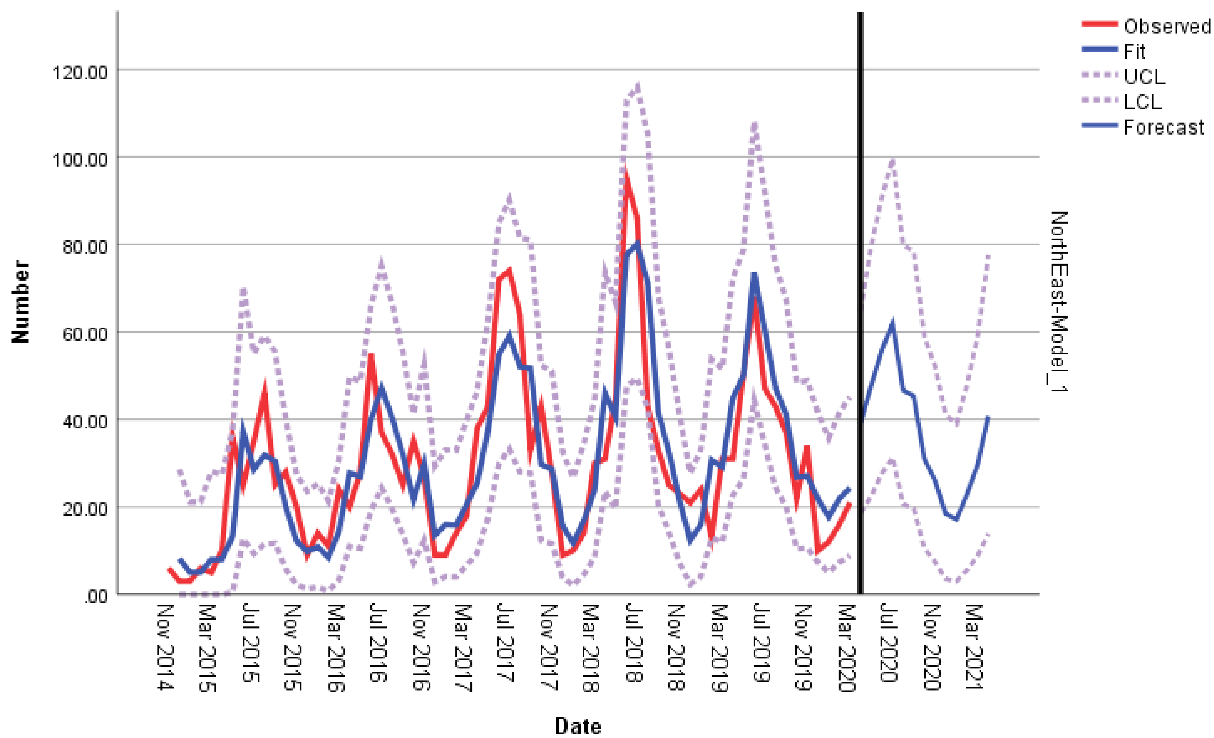


Figure 76. Sighting Incidents 12-Month Forecast – Northeast.

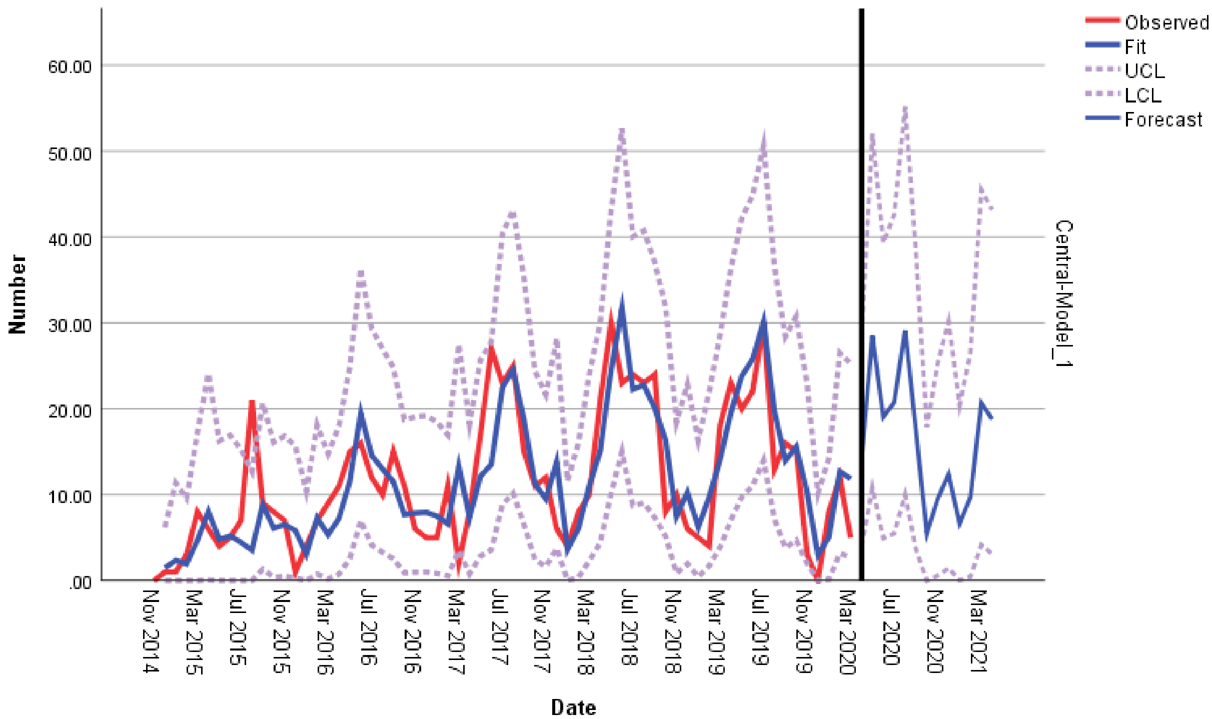


Figure 77. Sighting Incidents 12-Month Forecast – Central.

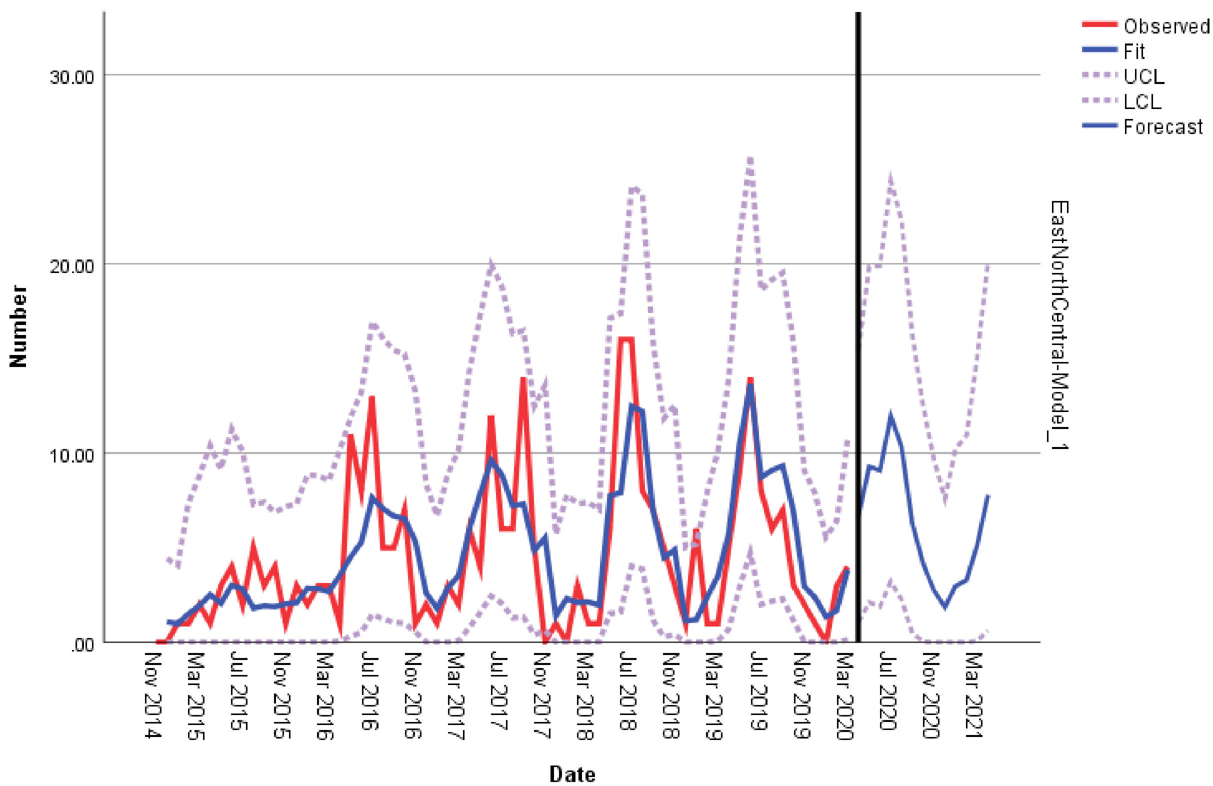


Figure 78. Sighting Incidents 12-Month Forecast – East North Central.

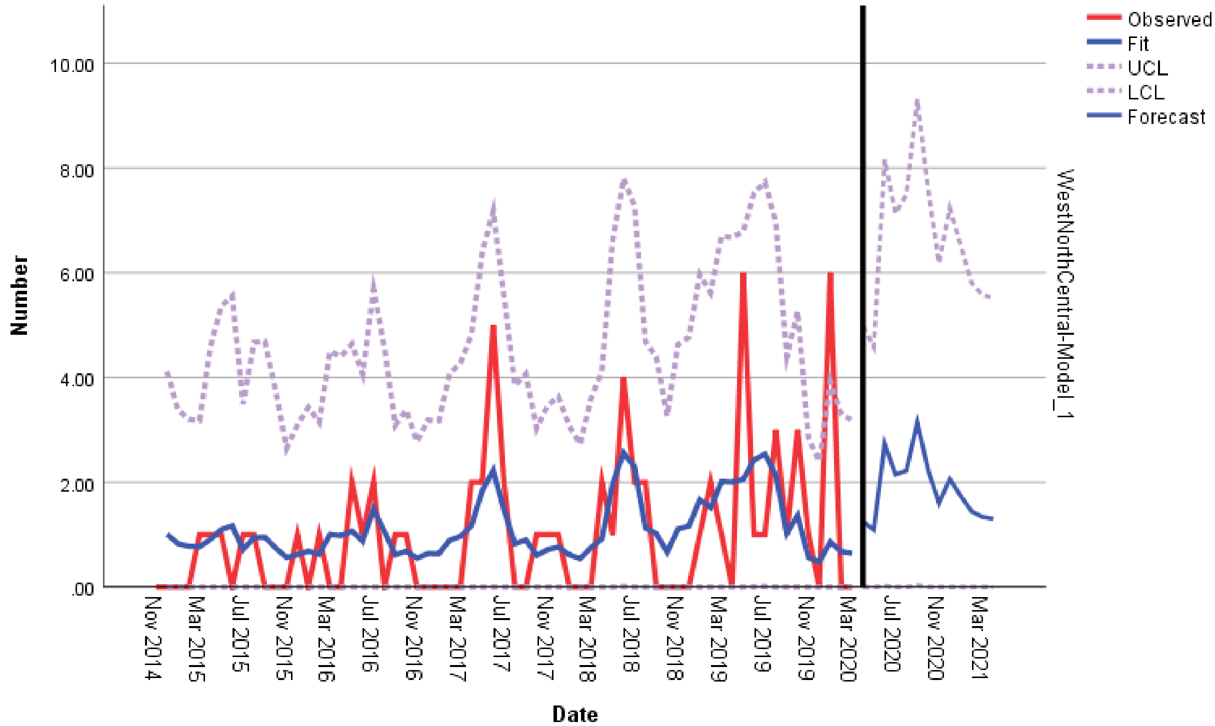


Figure 79: Sighting Incidents 12-Month Forecast – West North Central.

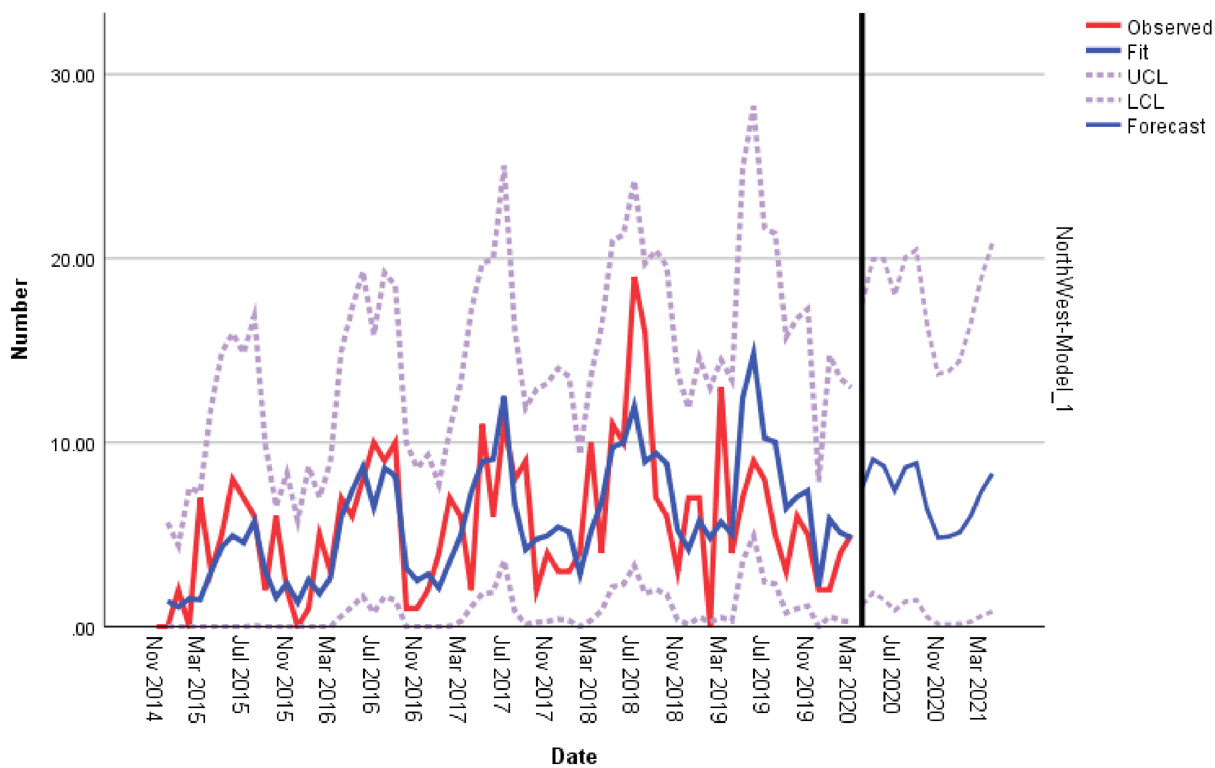


Figure 80. Sighting Incidents 12-Month Forecast – Northwest.

6.5 Data Gaps and Recommendations

UAS Registrations, Certificates, Waivers, and MLS operations. Overall, the quantitative and trend analyses provide useful findings of UAS registrations, certificates, waivers, UAS operations, and UAS incidents. The results show that UAS registrations, both for hobbyists and commercial users, increased noticeably since the implementation of UAS Registration Rule in December 2015. The registrations have been fluctuating over time, but the effect of LAANC, Operation and Certification requirements, and the effect of IPP on registration numbers seem to be apparent, especially for part 107 registrations. There is a gap in NPRMs' effects since it takes some time for the rule-makings to have impacts on the industry. Regardless, we noticed the increased registrations in mid-2020, possibly due to the publications of these NPRMs in 2019, especially part 107 registrations. The registration heat maps revealed that New York, Florida, Texas, and California are the four states with the highest registrations for both hobbyists and commercial users. There seem to have be more activities on the east side than the west side. Urban areas with high population densities and near large airports have more registrations by zip code.

According to the trend analysis of UAS certificates, the number of certificates for remote pilots seems to be impacted by Operation and Certification requirements for sUAS. Additionally, the number of certificate exams passed are consistent with the number of certificates issued. In addition, the trend analysis of UAS waivers shows a fluctuating pattern, but the impacts of LAANC and IPP could be observed. Most waiver applications use the simple and routine request process, and the waiver approval rate seems very low, except for 107.29 daylight operations.

The trend analysis of MLS operations and MLS incidents presents some interesting findings at the test sites. The number of MLS operations was too high in 2016 and then decreased over time. The trend for MLS operations was broken down by test site, aircraft type, operating altitudes, weight category, airspace class, LOS, and flight hours. In addition, the MLS incidents were also analyzed by operator, event, flight phase, and airspace class. It should be noted that the number of reported MLS incidents was too low to provide meaningful findings.

The main gaps in these analyses are the quality and format of the data. The lack of standardization limits the type of analysis that can be conducted, thus, limiting the findings. Following are the discussions of those gaps and recommendations for those data sets.

- Registration data: Part 107 registration variables can be further standardized to be usable for further analysis.
- Certification data: Remote pilot certificate data do not differentiate initial certification from re-certification; therefore, there is a possibility that these data only includes the number of initial certificates, not the total number of certificates actually issued. Clarification could be added to the data set. Additionally, remote pilot certificate data on the FAA FOIA are only available by quarter. Certificate data by day could be provided.
- Waiver data: Waiver application data are available only as textual data from the FAA FOIA library in PDF format. There is no information regarding approved and denied requests. Several waiver applications cover multiple regulations, which require standardizing the data for further analysis. Additionally, address fields should be standardized and broken into individual elements to aid geospatial analysis, such as mapping results to a specific locality. Standardization of variables is recommended to allow further analysis.
- MLS data: For MLS operations, aircraft type and operation variables should be standardized for further analysis. For MLS incidents, only 55 incidents or accidents were reported from May 2015 to June 2019. The incident reporting system may need to be updated.

- With more standardization for those data sets, they can be consolidated for further analysis. Appropriate multivariate statistical analyses could be conducted to examine the correlations among those variables and the effects of specific events on the changes of registrations, certificates, or waivers.

UAS Sighting Reports. The analysis results show the importance of UAS sighting reports in identifying violations in UAS operations and encounters between UAS and aircraft, helicopters, or towers. Those violations and encounters could lead to hazards, such as evasive maneuvers, mid-air collisions, or runway incursions, which eventually lead to incidents and accidents resulting in human injury, loss of property, or both. Having valid and usable sighting reports plays an important role in aviation analytics to identify the contributing factors and their effects on sighting incidents. The FAA could use the analytic results to develop necessary risk profiling and assessment mechanisms to evaluate the likelihood and severity of the hazards, based on which necessary risk mitigation strategies can be developed. As a result, appropriate rules, and regulations in the UAS registration, waiver request, and certification processes can be further developed or revised to ensure the safety of non-segregated UAS operations into the NAS.

GAO (2019) has investigated the UAS operations and how the FAA integrated UAS operations into its safety oversight framework. Based on the finding of this project, GAO recommended the FAA improving the data and communication, which is the key to enforcing compliance with UAS rulemakings (GAO, 2019). More specifically, GAO provides three recommendations to the FAA as follows:

- Identify UAS-specific education and training needs for inspectors and develop appropriate training to address any needs identified.
- Develop an approach to communicate key information more effectively to local law enforcement agencies regarding their expected role with regard to sUAS safety oversight.
- Recommend existing or new data and information needed to evaluate oversight activities and develop a mechanism for capturing these data as needed.

In order to improve the data and communication related to UAS operation safety, it is important to improve the quality of the UAS sighting reporting system. The current sightings report data collection processes have yielded data sets with inconsistencies in data element format and content reported, which limits quantitative analysis for risk assessment. Only the date, time, city, and state of each occurrence can be used in the available data formats. The sighting report is largely comprised of a narrative summarizing the incident reported by the spotters. This free-form field lacks uniformity and consistency that is necessary for extracting the requisite and valuable information and lacks explicit mechanisms to validate that the report captures all information desired for data analysis.

It is recommended to revisit the sighting report mechanism, identify necessary variables, and redevelop the reporting form. More checkboxes and/or radio buttons and multiple-choice questions should be used to improve the reliability and usability of the data through standardization. Text fields may still be used but only to identify and capture unique information that cannot be captured through the use of standardized fields. Truong and Choi (2020) used machine learning algorithms to predict the risk of UAS violations in the NAS and recommended specific variables, a scale, and a coding format that could be incorporated into the reporting process (Table 17). This instrument could be considered for further improvement of the sighting reporting process.

Table 17. Recommended variables and coding format for sighting reports.

Data Field	Subcategory	Measure	Coding Format
Incident Time	Day of week	Nominal	1 = Mon, 2 = Tue, …. 6 = Sat, 7 = Sun

	Time (Local)	Nominal	1 = Morning (06:00 - 11:59) 2 = Afternoon (12:00 - 16:59) 3 = Evening (17:00 - 20:59) 4 = Night (21:00 - 05:59)
Spot by		Nominal	1= Pilot (including passenger) 2 = Airport Operator, Tower, Tenants 3 = Police, Agents 4 = Citizen
Location		Nominal	1 = Airport (within 5 miles), 2 = Downtown, 3 = Suburban, Sea, Shore
UAS Profile	Type	Nominal	1 = Fixed wing, 2 = Single rotor, 3 = Multi rotors
	Size	Nominal	1 = Large (≥ 3ft), 2 = Small (< 3ft)
	Color	Nominal	1 = white, 2 = black, 3 = other color
	Lighting	Nominal	1 = flashing / 2 = continuous lighting
Violation Type *		Nominal	1 = flying beyond 400ft 2 = flying within 5 miles from an airport 3 = flying in restricted airspace
Incident Altitude (UAS)		Continuous	ft
Related Airport		Nominal	1 = Large Hub: 1% or more 2 = Medium Hub: 0.25% - 1% 3 = Small Hub: 0.05% - 0.25% 4 = Nonhub or Regional: 2,500 - 10,000 5 = Regional or GA Airport / 6 = Airbase
Distance from Airport		Continuous	Mile
Manned Aircraft Type		Nominal	1= Jet, 2= Prop, 3 = Helicopter/Blimp/Glider, 4 = Fighter / Military Jet
Manned Aircraft Operation		Nominal	1 = Landing or approach, 2 = departure, 3 = cruising
Position from Manned Aircraft**	Distance	Continuous	ft (Nearly hitting = 10)
	Direction	Nominal	1 = front, 2 = above, 3 = below, 4 = side, 5 = behind
Aircraft Involved		Binary	1 = yes, 2 = no
Reported as NMAC		Binary	1 = yes, 2 = no
Evasive Action		Binary	1 = taken, 2 = not taken
Law Enforcement Notification		Binary	1 = notified, 2 = not notified

7 Addendum 4: Technical Report – Waiver and NPRM Analysis

This task focuses on waiver and NPRM analysis toward future SMS data needs, and consists of the following subtasks:

- Describe the current FAA SMS approach with more focus on the safety risk management (SRM) component.
- Analyze waiver trend analysis reports and NPRM documents to map the document content to SRM steps.
- Identify the gaps between current waiver applications and NPRM documents to SRM process.
- Analyze the waiver request data to determine the trend of waiver request over time.
- Recommend content needed to meet the SRM steps.
- Recommend additional data for future data collection to meet the SRM requirements.

7.1 Introduction

The SRM process describes the systematic application of management policies, procedures, and practices to the activities of communicating, consulting, establishing the context, and assessing, evaluating, treating, monitoring, and reviewing risk. This process is undertaken to provide assurances that the risks associated with the operation of unmanned aircraft systems (UAS) have been managed to acceptable levels.

The purpose of this task is to describe the FAA SMS approach focused on the SRM process. Five steps in SRM (system analysis, identify hazards, analyze safety risk, assess safety risk, control safety risk) are analyzed and mapped to Part 107 waiver applications and NPRMs to identify gaps in the application data requirements and the needs to support SRM. The results can support regulators and applicants in identifying and mitigating to identify and mitigate all potential risks in future waiver review and operational planning.

The FAA provides information and guidance on air traffic policies and prescribes procedures for the planning, coordination, and services involving the operation of UAS in the United States' National Airspace System (NAS). The SRM process and its outcomes form part of the documented safety case necessary to obtain approvals for unmanned aircraft system operations.

7.2 Research Questions

What SMS processes govern the analysis of waiver applications and the data requirements to validate each?

7.3 Safety Risk Management (SRM) Process Descriptions

SRM is a formalized, proactive approach to system safety. At a minimum, SRM includes the following processes: a) System description and analysis, b) Hazard identification, c) Safety risk analysis, d) Safety risk assessment, and e) Safety risk controls (Figure 81). SRM provides a means to identify, analyze, assess, and control safety risk in the aerospace system (FAA, 2015).

Both ICAO and the FAA provide similar definitions of a hazard: any existing or potential condition that can lead to injury, illness, or death to people; damage to or loss of a system, equipment, or property; or damage to the environment. A hazard is a condition that is a prerequisite to an accident or incident (FAA, 2015). Hazards may be the result of systems that are deficient in their design, technical function, operating environment (including physical conditions, airspace, and air route design), human operator failure/error, human-machine interface problems or interactions with other processes and systems, operational procedures limitations, or maintenance procedures limitations/design (ICAO, 2013).

Hazards present conditions which may ultimately result in an unwanted outcome that affect operations in a way that results in degraded system performance, ultimately resulting in an unwanted outcome. Hazards in the system and its operating environment must be identified, documented, and controlled to subsequently enumerate the risks associated with the hazards to best support subsequent risk assessment (ICAO, 2013). The SRM process will be applied to

- Initial designs of systems, processes, organizations, and services
- The development of new or changed operational procedures
- Planned changes to operational processes

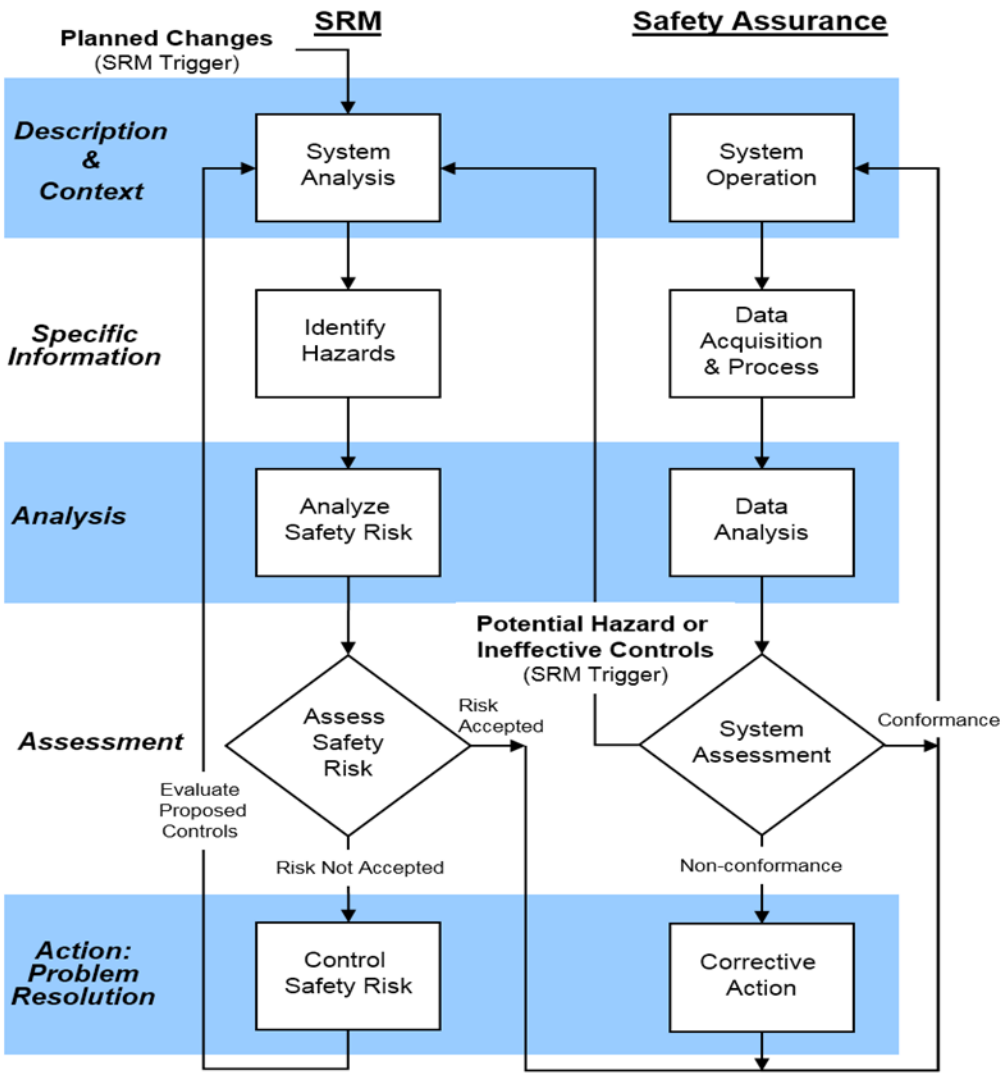


Figure 81: FAA SMS process: Interface between SRM (safety risk management) and SA (safety assurance).

7.4 Methodology

7.4.1 Data Sources

This effort utilized the existing available data sources for Unmanned Aircraft Systems (UAS), including Waiver Safety Explanation Guidelines (WAG) for Part 107 Waiver Applications, Waiver Trend Analysis for Part 107 waivers, NPRMs database, FAA Safety Management System, FAA Unmanned Aircraft

Systems Safety Risk Management Policy, and Federal Aviation Administration Safety Risk Management Guidance: The 5 Step Process (AVP-300-003-JA1).

Given a large number of Part 107 waiver approval data, with more than 4200 approval letters and lack of access to denied waiver applications, for this project, the FAA waiver applications trend analysis reports were used as the main data source for Part 107 waiver applications. These waiver trend analysis reports were constructed by the FAA to capture waiver application elements from past approvals and denials (FAA, 2020c).

7.4.2 Data set Description

The data set includes UAS SRM requirements, SMS process requirements, Part 107 waiver applications trend analysis reports, type of waiver operations, NPRMs, times of NPRM changes, and a final rule. In particular, the following documents were used in this study:

- Beyond Visual Line of Sight (107.31) Waiver
- OOP Operations Over People (107.39(a)) Waiver
- Night Operations (107.29) Waiver
- FAA-2018-1084-0001- 7 CFR Part 48- External Marking Requirement for Small Unmanned Aircraft
- FAA-2018-1086-0001- 14 CFR Part 107- Safe and Secure Operations of Small Unmanned Aircraft Systems
- FAA-2018-1087-0001- 14 CFR Part 107- Operation of Small Unmanned Aircraft Systems Over People
- FAA-2019-0364-0001- 14 CFR Part 107 - Exception for Limited Recreational Operations of Unmanned Aircraft
- FAA-2019-1100-0001- 14 CFR Parts 1, 47, 48, 89, 91, and 107- Remote Identification of Unmanned Aircraft Systems

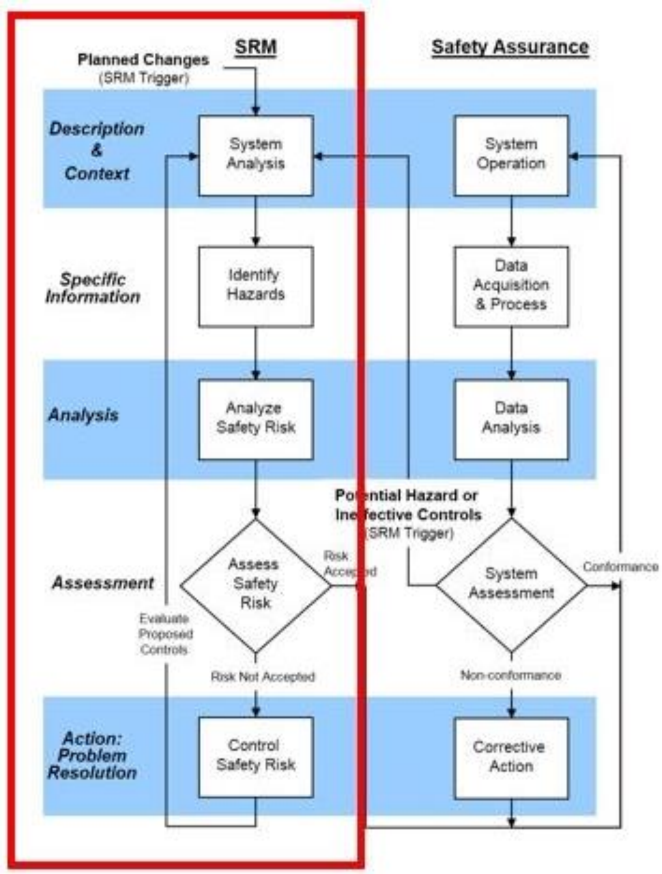
7.4.3 Node Hierarchy of SRM Process

The node hierarchy of the SRM process was developed based on the FAA and ICAO high-level safety risk management process descriptions, as shown in Table 18. Although the FAA and ICAO choose to present the components of SRM in slightly different terms, they share four common steps: hazard identification, risk analysis, risk assessment, and risk control and mitigation. Figure 82 shows the most current FAA SRM process with five steps and how those steps are related to the Safety Assurance process. For the purpose of this study, the five-step SRM used for this analysis were: system analysis, identify hazards, analyze safety risk, assess safety risk, and control safety risk.

The node hierarchy was developed based on these five steps, as presented on the right-hand side of Figure 82. Each parent node represents one step in the SRM process. Child nodes for each step were developed based on the FAA guidelines and regulations on SMS listed above. The node hierarchy was also reviewed by an external subject matter expert and revised carefully based on his feedback. Table 19 presents the complete node hierarchy for SRM steps for UAS operations.

Table 18. Comparison of high-level safety risk management process descriptions—FAA and ICAO.

FAA	ICAO
System description and task analysis	
Hazard identification	Hazard identification
Safety risk analysis	Risk analysis probability
	Risk analysis severity
Safety risk assessment	Risk assessment and tolerability
Safety risk control and mitigation	Risk control/mitigation



SRM

- a. System Analysis
  - Function and purpose of the system/item being assessed
  - List of Activities
  - Workplace Conditions
- b. Identify Hazards
  - Actual Sources Possible Causes of Hazards
- c. Analyze Safety Risk
  - Defining Risk
  - Determining Credible Hazard Effect
  - Identifying Controls Reducing Hazards Causes or Effects
  - Mitigating Risk Controls
  - Preventative Risk Controls
  - System State
- d. Assess Safety Risk
  - Plotting Risk for Each Hazard
  - Prioritized Risks Prioritized Treatment
  - Risk Levels and Definitions
- e. Control Safety Risk
  - Accept the Risk
  - Approved Control Strategies
  - Assigned Responsibilities
  - Collected Additional Hazard Data
  - Elimination Mitigation Strategies
  - Implemented Control Strategies
  - Re Evaluated Control Strategies

Figure 82. Node Hierarchy of SRM Process.

Table 19. Parent and Child Nodes Hierarchy of SRM Process.

a. System Analysis		
	Function and purpose of the system/item being assessed	
	List of Activities	
		Agricultural
		Commercial Company Use
		Education
		Energy
		Environmental
		Humanitarian Disaster Response
		Law and Border Enforcement
		Movie Filming
		Personal Use
		Sports and Media Broadcasting
		Transportation
		Wildlife Monitoring
	Workplace Conditions	
		Ambient Environment
		Assumptions Made About System Assessed and its Interaction in Aerospace System
		Company Rules
		Contracted and Purchased Products and Services
		Existing Safety Risk Controls
		Human Factors Requirements for Ops & Maintenance
		Interactions Between Items Listed Above
		Interactions with Other Systems in Broader Aerospace System
		Maintenance Environment
		Operational Environment
		Personnel, Equipment, and Facilities Necessary for System Operation
		Related Procedures That Define Guidance for Operation and Use of System
		Supervision -Management (Controls)
		Systems Processes Procedures and Performance
		Training (Formal, OJT, Recurrent etc.)
b. Identify Hazards		
	Actual Sources Possible Causes of Hazards	
		Ambient Environment
		Assumptions About System and its Interaction in Aviation System
		Contracted and Purchased Products and Services
		Equipment Failure Malfunction
		Existing Safety Risk Controls
		Human Factors Requirements for Ops and Mx
		Interaction with Other Systems and Sub Systems in Broader Aviation System
		Interactions Between Items Listed Above
		Maintenance Environment
		Operational Environment
		Personnel Equipment and Facilities Necessary for System Ops
		Related Procedures That Define Guidance for Ops and Use of System
		Systems Processes Procedures and Performance
c. Analyze Safety Risk		
	Defining Risk	
		Determining Likelihood

		Determining Severity
	Determining Credible Hazard Effect	
	Identifying Controls Reducing Hazards Causes or Effects	
		Hardware
		Other Tools
		Policies
		Procedures
		Software
	Mitigating Risk Controls	
	Preventative Risk Controls	
	System State	
		Conditional Example IMC vs VMC
		Operational and Procedural VFR vs IFR
		Physical Example Closed vs Open Runways
d. Assess Safety Risk		
	Plotting Risk for Each Hazard	
	Prioritized Risks Prioritized Treatment	
	Risk Levels and Definitions	
		High Risk
		Low Risk
		Medium Risk
e. Control Safety Risk		
	Accept the Risk	
	Approved Control Strategies	
	Assigned Responsibilities	
	Collected Additional Hazard Data	
	Elimination Mitigation Strategies	
	Implemented Control Strategies	
	Re evaluated Control Strategies	

7.4.4 Coding process

The team performed qualitative analysis using NVivo, a qualitative data analysis software tool. It supports the analysis of qualitative data in five principal ways (Bazeley, 2007): a) managing and organizing data, b) managing ideas, c) querying data, d) graphically modeling the ideas and concepts that are being built from the data, and e) reporting from the data.

NVivo is designed for qualitative researchers who need deep levels of analysis for small or large volumes of data. NVivo includes a single storage location that provides easy access to material and the ability to handle large amounts of data with consistent coding schemes. It is possible to import documents directly from a word processing package and easily code them on screen. Coding stripes can be made visible in the margins of documents so that the researcher can see at a glance, which codes have been used and where. However, researchers and analysts encounter many deficiencies during coding and in understanding their data that may obstruct analysis. These deficiencies include information availability, missing information, confidence in judgment, and inconsistency when repeated evaluations of the same data tend to differ.

7.4.4.1 Interactive coding

The team used interactive coding techniques because the Part 107 waiver applications and NPRMs data sets are unstructured. The documents were coded separately to the node hierarchy. The coders reviewed those qualitative reports, highlighted related sentences, phrases, or paragraphs in each document, and linked them to each item in the node hierarchy. NVivo recorded the links, the references between the nodes, the source documents. The references for this connection were recorded as numeric data in the software for analysis purposes.

7.4.4.2 External Subject Matter Expert (SME)

An external SME was invited to participate in this task, due to the nature of the qualitative research and lack of objectivity in the coding process. The SME is an expert in the field of aviation safety and SMS, who holds a Ph.D. in Aviation with a specialization in aviation safety. He also has extensive research experience in aviation safety and small UAS risk perception. He is an experienced pilot with many flight hours. He reviewed the node hierarchy and provided feedback for improvement. He also acted as the second coder and coded the data based on that node hierarchy. His input was used to verify the node hierarchy and evaluate the reliability of the codes.

7.4.4.3 Validating and testing the reliability of the codes (inter-rater reliability)

A coding comparison query was run to compare coding done by two coders to measure the interrater reliability, or degree of agreement for coding between the coders through the use of the "Kappa coefficient," in order to test the reliability of the codes. A Cohen's Kappa coefficient over 0.75 indicates excellent agreement; 0.40 to 0.75 indicates fair to good agreement, and less than 0.4 indicates poor agreement. The codes were revised if the inter-coder reliability was not satisfactory. In this case, both coders discussed the nodes to make sure they had consistent understanding of the nodes before revising their codes. Then, the reliability assessment was repeated. Table 20 shows the result of the coding comparison query from NVivo with its Cohen's Kappa coefficient.

Table 20. Cohen's Kappa coefficient.

Kappa value	Interpretation
Over 0.75	Excellent agreement
0.4 to 0.75	Fair to good agreement

7.4.5 Analysis steps

The coders used NVIO to analyze the data, after organizing the raw data from the data set into themes and going through the coding processes. Analysis techniques used in this project include word cloud, word frequency, hierarchy chart, and comparison diagrams. Visualizations generated by NVivo, such as charts and diagrams, were used mainly to report the results.

7.5 Analysis results

7.5.1 Word Cloud

By using the word cloud, the research team can list the most frequently occurring words or concepts in the sources. The most frequently used words in the data set include sUAS, remote pilots, identification, compliance, to name a few, operations, proposed, requirements, and rules, as depicted in Figure 83.

Figure 83. Word Cloud.

7.5.2 Tree Map

A tree map is a diagram that shows hierarchical data as a set of nested rectangles of varying sizes. The tree map feature displays up to 100 words as a series of rectangles, where frequently occurring words are in larger rectangles, as illustrated in Figure 84. The tree map shows similar results as seen in the word cloud, with more specific breakdown of the word frequency.

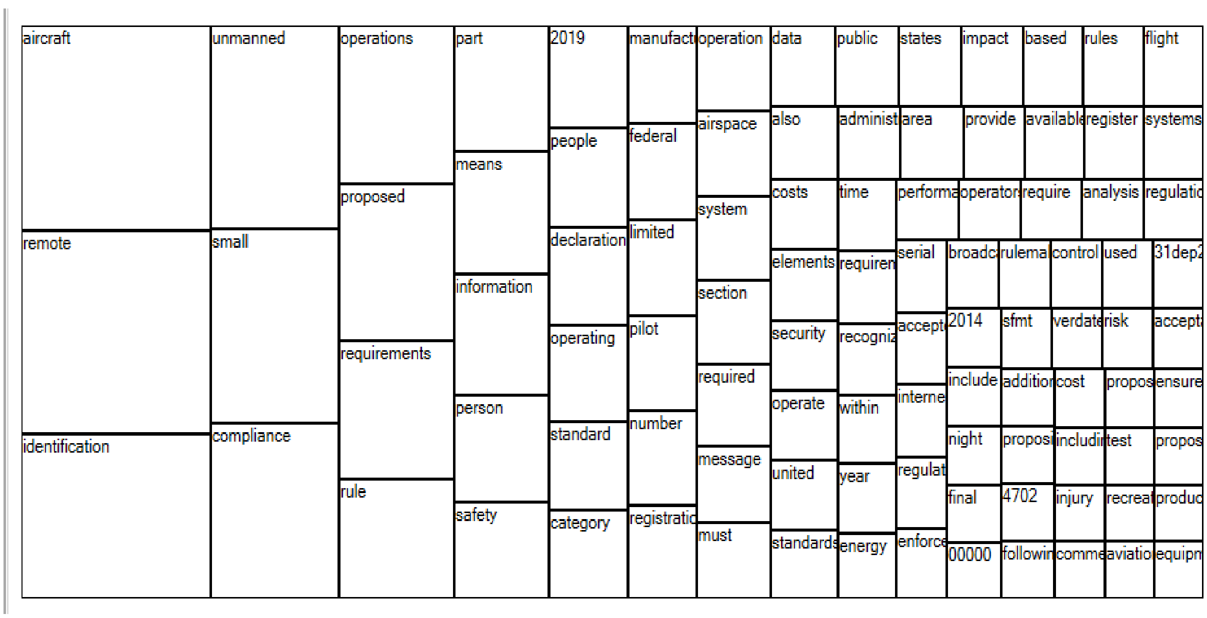


Figure 84. Tree Map.

7.5.3 Hierarchy Chart

Hierarchy charts are colored by hierarchy and sized by the number of items coded (coding references) to a node in the hierarchy. This means that each different parent item in the hierarchy is assigned a different color, and the child and grandchild items are lighter shades of the parent color. The items are sized by the number of items coded. This combination makes it easy to differentiate the branches of our hierarchy.

This study's hierarchy chart is presented in Figure 85. *System analysis* has the most coding references, so it is the largest area and has the darkest color. *Identify hazards* is smaller than *System analysis* and has a lighter color because it has fewer coding references. Similarly, *control safety risk* and *analyze safety risk are* smaller than *identify hazards* and have lighter colors because they have fewer coding references. Finally, *assess safety risk* is the smallest of all because it has the least coding references.

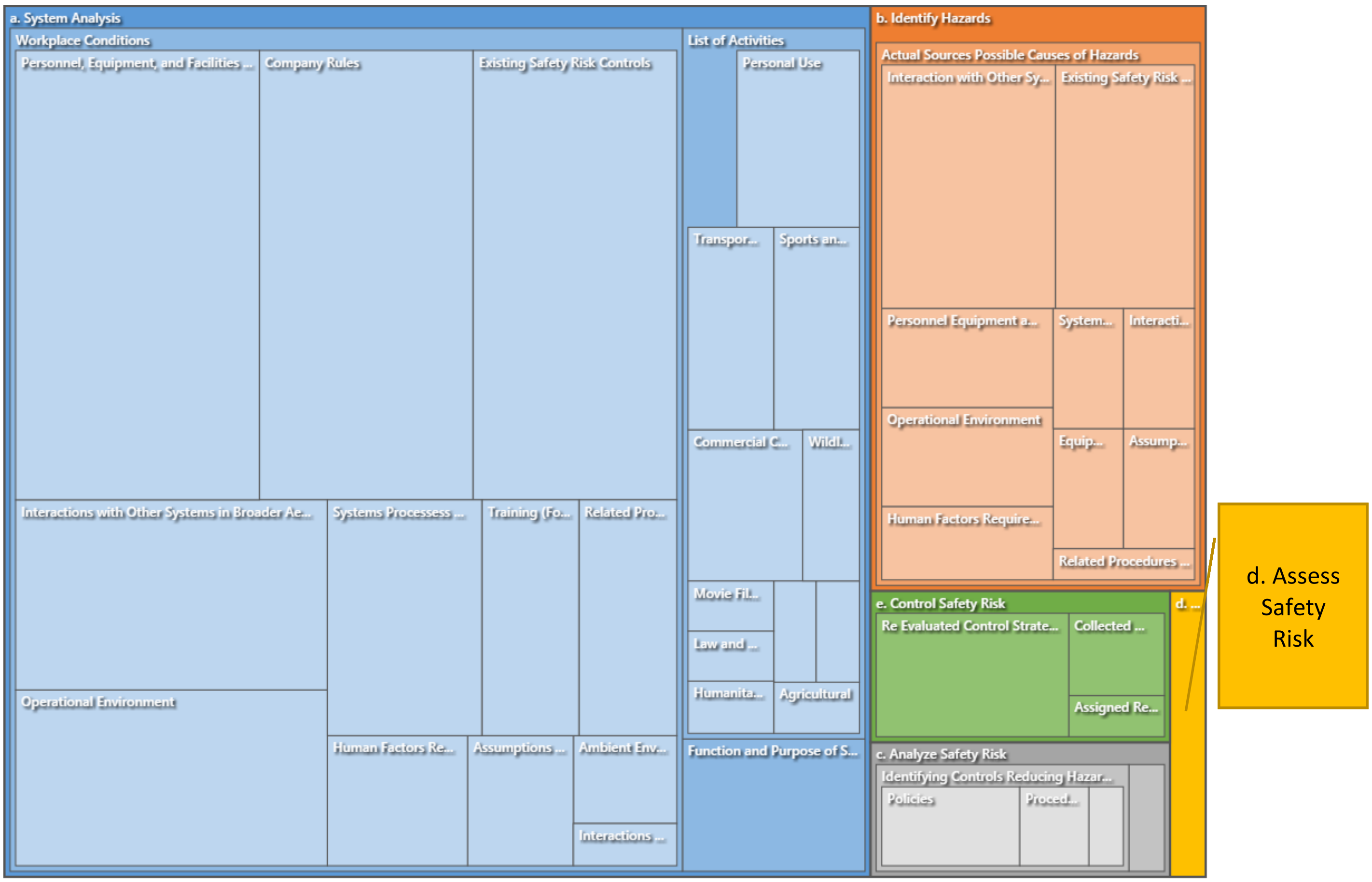


Figure 85.Hierarchy Chart.

7.5.4 *Comparison Diagrams*

In order to further identify the gaps between the rulemakings and waiver requests and the SRM process, the research team employed comparison diagrams based on the code to compare the document sources at particular nodes representing SRM steps. Figure 86 presents the comparison diagrams for the five SRM steps and corresponding documents. These figures show the steps covered by each rulemaking. For example, we can see that steps a, b, and c are covered by most rulemakings, while steps c and are only covered by one or two rulemakings. Table 21. Comparison matrix. summarizes the SRM steps covered by each document. It appears that steps a (System Analysis), b (Identify Hazards), and c (Analyze Safety Risk) are covered in most or all waiver applications trend analysis reports and NPRMs. Two SRM steps that are insufficiently covered include steps d (Assess Safety Risk) and e (Control Safety Risk).

Therefore, the hierarchy chart and diagram comparison analysis reveals a lack of information on the Assess Safety Risk and Control Safety Risk of the SRM process. In other words, those documents do not cover necessary information regarding plotting risk for each hazard, prioritized risks, prioritized treatment, and risk levels and definitions in Step d, and the information regarding accepting the risk, approved control strategies, assigned responsibilities, collected additional hazard data, elimination mitigation strategies, implemented control strategies and re-evaluated control strategies in Step e. Detailed recommendations regarding providing additional information in those documents will be covered in Section 7.6.

Table 21. Comparison matrix.

Documents	**SRM steps**				
	a. System Analysis	**b. Identify Hazards**	**c. Analyze Safety Risk**	**d. Assess Safety Risk**	**e. Control Safety Risk**
Beyond Visual Line of Sight (107.31) Waiver Trend Analysis	X	X	X		
Operations Over People (107.39(a)) Waiver Trend Analysis	X	X	X		
Night Operations (107.29) Waiver Trend Analysis	X	X			
FAA 2019 1100 - Remote Identification of Unmanned Aircraft Systems	X	X	X		X
FAA 2019 0364 - Exception for Limited Recreational Operations of Unmanned Aircraft	X	X			
FAA 2018 1084 - Special Evaluation Assistance for Rural Communities and Households Program	X	X	X		
FAA 2018 1087 - Operation of Small	X	X	X		X

Unmanned Aircraft Systems Over People -					
FAA 2018 1086 - Safe and Secure Operations of Small Unmanned Aircraft Systems	X	X	X	X	

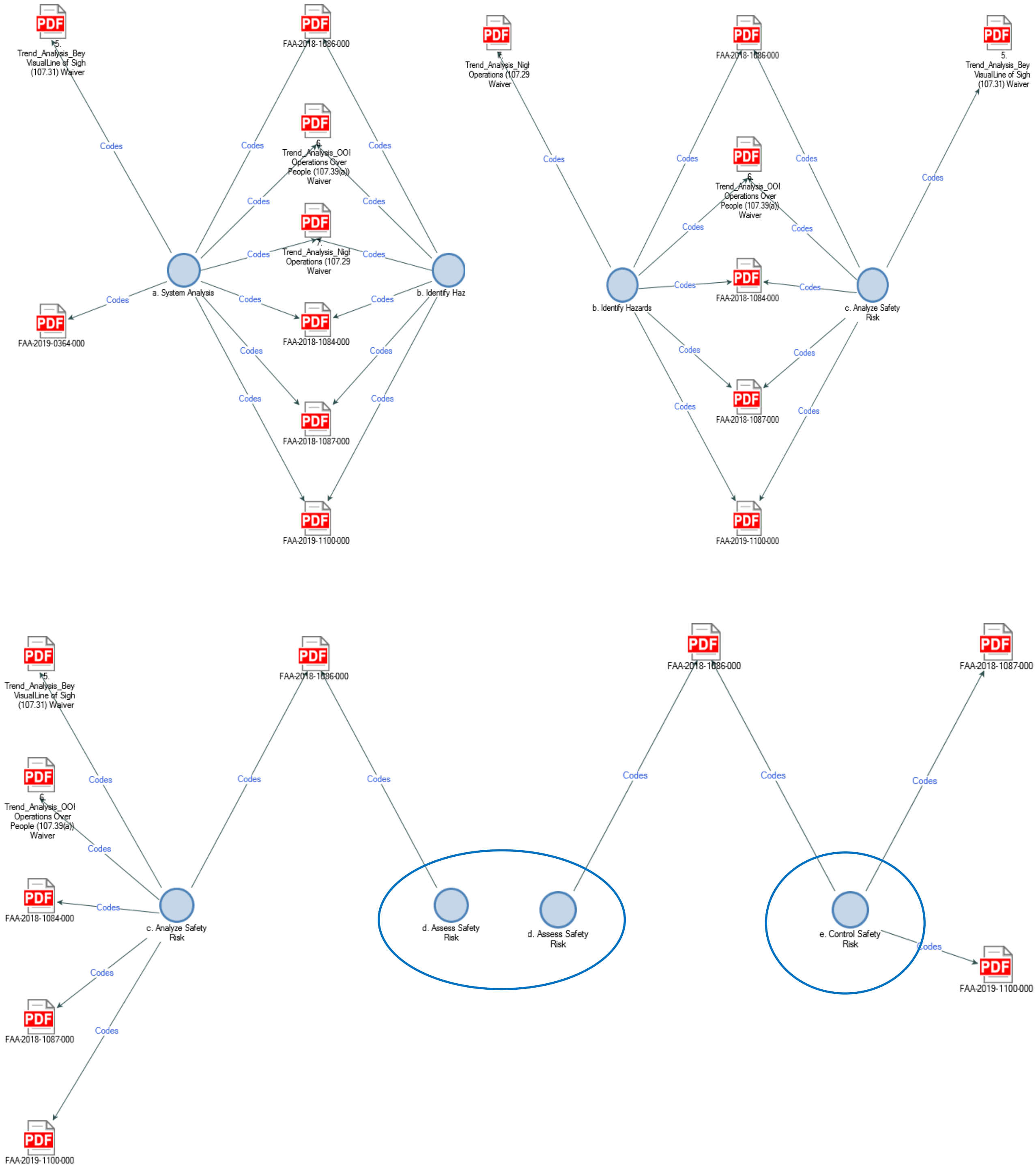


Figure 86. Comparison Diagrams.

7.6 Recommendations on Data Requirements for SMR Process, Waiver Requests, and NPRMs

The qualitative analysis results uncovered gaps between the SRM process and waiver applications trend analysis reports and published NPRMs. More specifically, while most documents sufficiently cover the first three steps (system analysis, identify hazards, and analyze safety risk), the last two steps (assess safety risk and control safety risk) seem to be lacking. This section presents several recommendations regarding SRM practices that can be used to further ensure the safety of UAS operations in the NAS.

Understanding the complexity of challenges to be faced in the safety risk management of UAS requires consideration of the social, psychological, political, and economic factors associated with the broader integration of UAS into society. The safety risk management process can be used to support a range of operational, financial, or regulatory decisions concerning UAS. In other words, a safety risk management document can be considered an effective tool to summarize (record) the safety analysis, capture the prioritized hazards and associated risk mitigations, and serves to enable the management team to understand the change, associated risks, mitigation strategies and commitment to fund and implement the mitigation strategies (Stolzer, Halford, & Goglia, 2011).

The primary safety risks that need to be addressed before UAS can be introduced in Non-Segregated Airspace without degrading safety are the *risks of collision with other airspace users* and *the risk of collision with objects on the ground.* The objective of the risk assessment process is to comprehensively characterize the safety risks associated with UAS operations and based on this information, determine which of the characterized risks can be tolerated and which of the characterized risks require mitigation (treatment). The risk assessment process comprises the subprocesses of risk identification, risk analysis, risk evaluation, and risk treatment (Clothier & Walker, 2015).

7.6.1.1 Proposed Action and Process to fill the Gaps of "*Assess Safety Risk and Control Safety Risk*"

The guidelines for risk assessment should be conducted and included in the proposed rules to provide appropriate assurances, review risk assessments, and support the applicants' safety case (e.g., UAS operators). The objective is to ensure that risks associated with flight operations hazards are systematically and formally identified, assessed, and managed within acceptable safety levels. A UAS safety risk assessment may have to deal with the entire UAS lifecycle, including a) specification, b) manufacturing, c) implementation, d) transition to operational service, e) operational service, and f) decommissioning.

After the risk analysis is completed, the risk assessment will take one step further by performing a risk evaluation. The safety risk index in terms of probability and severity of the hazard is calculated to determine the level of risk. The safety practitioner or functional manager will decide if the risk is acceptable or requires mitigation. In case the safety issue requires mitigation, the mitigation strategies are developed to treat the risk (Stolzer, Halford, & Goglia, 2011).

The following safety risk assessment and mitigation process, as shown in Table 22, needs to be developed and included in the proposed rules to guide UAS operators to assess safety risk and develop detailed risk treatment (based on risk) associated with UAS operations.

Table 22: Safety Risk and Mitigation Process.

1	A commonly agreed risk criteria framework for UAS operations defined for judging the acceptability of risk
2	A procedure to prioritize identified hazards for risk mitigation actions
3	A procedure for periodic review of existing risk mitigation records
4	A procedure to account for mitigation actions whenever unacceptable risk levels are identified

5	A program for systematic and progressive review of all UAS safety-related operations, processes, facilities, and equipment subject to the hazard identification and risk mitigation (HIRM) process as identified by the organization (ICAO, 2013)

7.6.1.2 Risk criteria

The integration of UAS into the National Airspace System (NAS) could pose a risk to human safety deriving from two potential causes: midair collisions and ground asset damage (including pedestrians and inhabited buildings). For example, a collision may occur between a UAS and a transient aircraft (e.g., commercial flights, regional jets, and general aviation). This collision may injure or result in fatalities onboard the transient aircraft, while simultaneously generating debris that could potentially affect bystanders on the ground (Atkins, Ollero, & Tsourdos, 2016). Thus, to ensure the safe integration of UAS into the NAS, it is crucial for an operator or regulator to conduct a risk analysis of the critical hazards such as midair collisions and low-altitude operational areas, particularly in the vicinity of people and inhabited buildings. The risk assessment framework can be developed to estimate the risk to human life incurred from a given UAS operation (Atkins et al., 2016). The risks associated with a given UAS operation can be defined by characterizing them into two broad categories: (a) ground risks; and (b) air risks. The risk criteria framework for UAS operations can be established to judge the acceptability of risk. "UAS must operate safely, efficiently, and compatibly with manned aircraft operation in the airspace so that the overall safety of the airspace is not degraded. The fundamental safety requirement for the UAS is to provide an acceptable level of risk for people and property in the air and on the ground" (RTCA, 2007, p.1).

Figure 87 and Figure 88 show examples of a UAS risk analysis process comprising risk to human life on the ground and in the air with the FAA direct involvement (FAA, 2018).

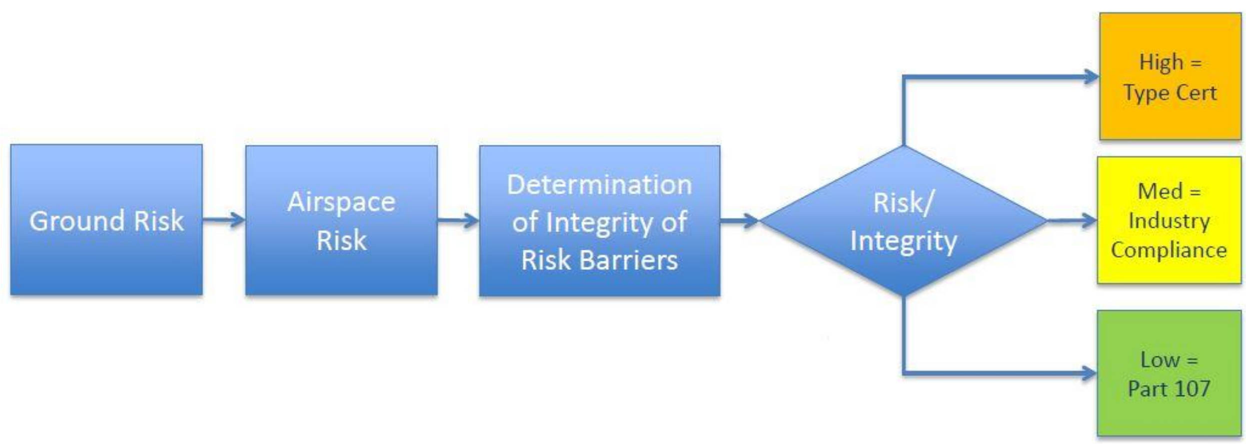


Figure 87. UAS Risk Analysis Process (FAA, 2018)

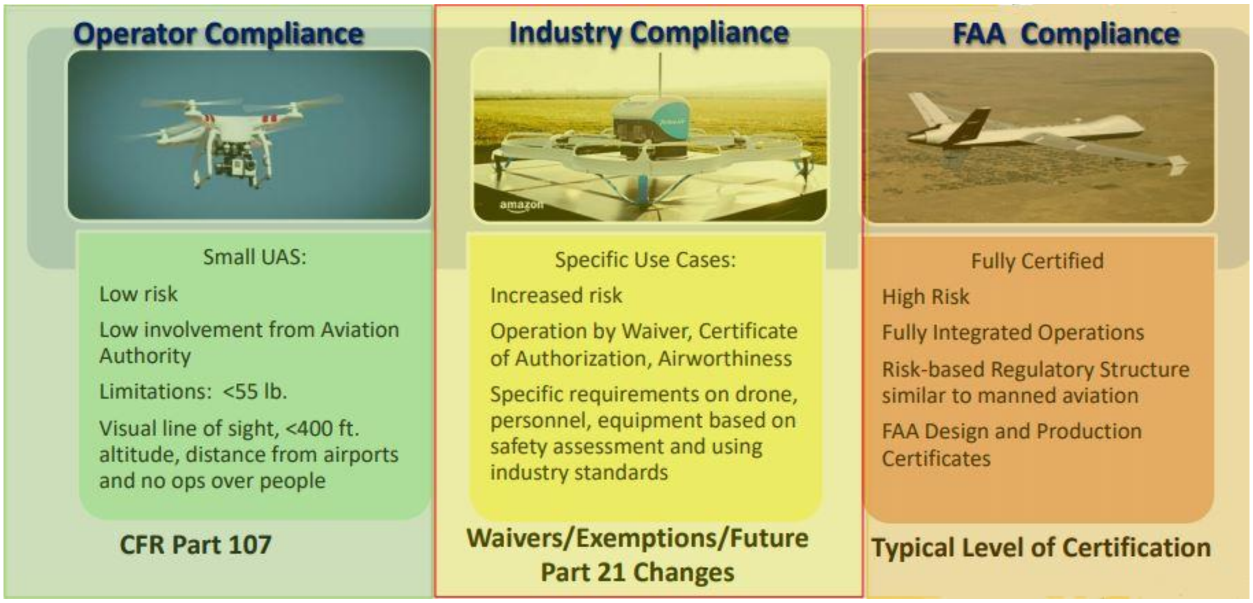


Figure 88. Risk-Based FAA Direct Involvement (FAA, 2018)

The following risk matrix can be categorized by taking into consideration both ground risks and air risks in order to accurately assess risk levels. The risk matrix in Figure 89 is based on the FAA's risk matrix in SRM Policy 8040.4B and shared by Department of Defense (DOD) and Department of Homeland Security (DHS). While the X-axis describes the Severity, the Y-axis indicates Likelihood. Numbering is added for ease of cross-reference and tracking (FAA, 2019).

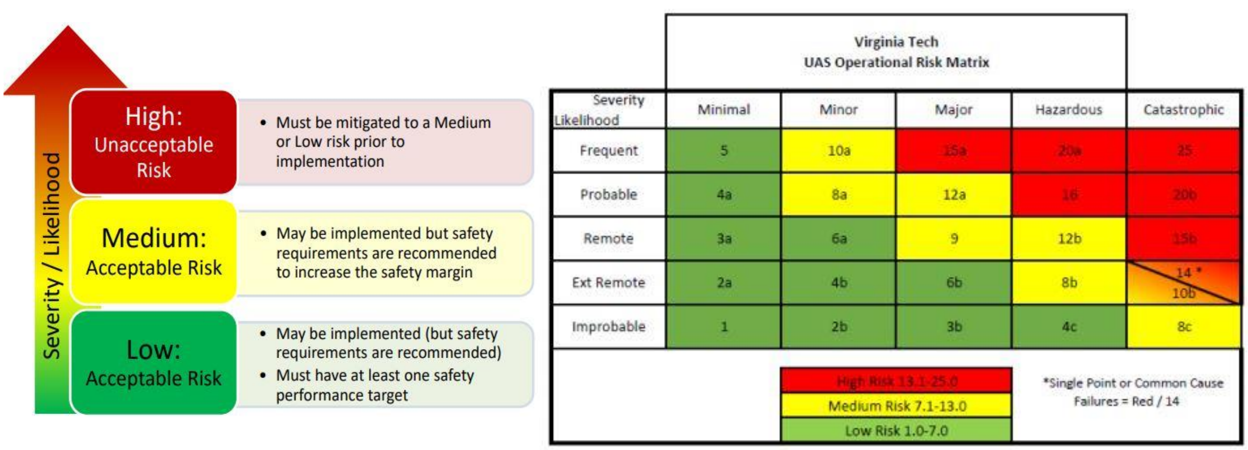


Figure 89. Risk matrix for assessing risk levels (FAA, 2018; FAA, 2019)

A range of qualitative and quantitative scales have been used to describe levels of risk. For example, MIL-STD-882D (DoD 2010a) assesses risk on the qualitative ordinal scale: low, medium, serious, and high. The component measures of consequence and of likelihood then need to be mapped to an appropriate level of risk. A risk matrix is the most common method for illustrating this mapping, as shown in Figure 90.

	CATASTROPHIC	CRITICAL	MARGINAL	NEGLIGIBLE
FREQUENT	HIGH	HIGH	SERIOUS	MEDIUM
PROBABLE	HIGH	HIGH	SERIOUS	MEDIUM
OCCASIONAL	HIGH	SERIOUS	MEDIUM	LOW
REMOTE	SERIOUS	MEDIUM	MEDIUM	LOW
IMPROBABLE	MEDIUM	MEDIUM	MEDIUM	LOW
ELIMINATED	ELIMINATED			

Figure 90. Example of a risk matrix as per MIL-STD-882D (2010a).

8 Addendum 5: Technical Report – Visual Sightings Database Validation

8.1 Introduction

This research task sought to evaluate UAS user activity within the National Airspace System using UAS detection technology. An additional objective of this research was to evaluate the accuracy of UAS sighting reports using aviation traffic data coupled with UAS detection technology.

8.1.1 Background

A 2018 National Academies of Science report, "Assessing the Risks of Integrating Unmanned Aircraft Systems into the National Airspace System," highlights the need for a data-driven approach to inform policy decision-making. In the report, the authors assert that successful UAS integration into the National Airspace System is reliant on the creation of probabilistic risk assessment. "Accepting risk is far easier when the risk is well-quantified by relevant empirical data" (National Academy of Science, 2018, p. 41). Nevertheless, the authors acknowledge the limitations associated with collecting needed data, noting that such data are "expensive to collect, scarce, or non-existent, and in some cases not very reliable. . ." (National Academy of Science, 2018, p. 39). Specific data gaps were noted for UAS-encounter statistics as well as low-altitude environmental data.

The Commercial Drone Alliance (CDA) recognizes the dearth of UAS data in low altitude airspace, ". . . additional effort to properly evaluate the low-level risk that UAS operations present to manned aircraft is necessary" (Commercial Drone Alliance, 2020, para. 7). The CDA points out that the lack of available empirical data to accurately assess low level airspace risk creates a condition in which "the FAA is inclined to be exceptionally conservative," potentially falling behind other nations in implementing shared low-altitude operations (CDA, 2020, para 8). The CDA goes on to recommend:

> . . . conduct[ing] a sophisticated, national study of the operational risks associated with low-altitude UAS operations below 400 feet AGL. The risk analysis would consider factors such as traffic density, trajectories, weather, population density, terrain, land use and zoning, building heights, and other local factors for the entire United States. . . The federal government could conduct an airspace characterization effort leveraging nationwide radar and other surveillance assets (from FAA, DOD, and other sources) to provide an assessment of the relative risk presented by UAS and AAM operations. (CDA, 2020, para 9)

Frederick Roggero (2018) succinctly codifies these problems: "Currently, there is no means for any central entity to accurately collect, track, record, report, disseminate, or analyze data regarding how many total UAS flights occur without having a safety incident or terminating in a mishap" (p. 3).

Recognizing these limitations, the research team sought to *specifically* address data deficiencies by leveraging UAS detection technology to provide empirical data about low-altitude UAS operations *actually taking place*.

8.1.2 Research Questions/Goals

The research team sought to answer the following questions:

- Is there a relationship between the quantity of UAS sighting reports, registered UAS population, and drone detection census?
- Where are UAS operations taking place?
  - Airspace
  - Altitude
  - Launch locations

  - Proximity to Aerodromes, Approach
- Are UAS operations compliant with existing regulations?
  - Altitude limits
  - LAANC authorizations
  - Line of sight?
- Are pilot sighting reports of unmanned aircraft a valid measure of UAS-aircraft NMAC risk?
- To what extent do close encounters between aircraft and UAS occur that are not reported?

8.2 Methods

The research team leveraged historical UAS detection data from DJI AeroScope sensors placed across the country at various convenience sample locations. Detection data sets were furnished for the project by a series of UAS detection service companies.

8.2.1 AeroScope

Manufactured by drone-maker DJI, the AeroScope is a comprehensive UAS detection solution designed to detect and glean information from UAS datalink communication, including flight status, telemetry, and other information in real-time (DJI, 2020). The device is designed for continuous, passive monitoring of unmanned aircraft at ranges up to 50km (DJI, 2020). Flight data is stored on a cloud-based server, which facilitates monitoring, system control, and data analysis tools (DJI, 2020). The AeroScope does not provide a complete detection solution, as the device reportedly only detects unmanned aircraft manufactured by DJI (Goode, 2017). According to Drone Industry Insights, DJI drones account for approximately 77% of U.S. drone sales, commanding a market share nearly 20 times that of the closest competitor (Schmidt & Vance, 2020).

8.2.2 Data Collection

Primary data for the study was collected from a G-18 AeroScope device located at Dallas-Fort Worth International Airport, Texas. UAS flight activity was collected from 15:30 (ET) August 22, 2018 to January 31, 2020 at 23:00 (ET). The device was operated continuously during the sampling period, with minimal interruptions for service or maintenance functions. The research team was provided direct, server access to the data set. The research team performed all data inquiries, downloads, data management, and analysis functions.

8.2.3 Drone Census

During the sampling period, the AeroScope detected a total of 12,520 unique DJI serial numbered UAS. During the sampling period, the system registered a total of 162,162 separate flights. Detections ranged from .03 NM to a maximum of 62.32 NM from the sensor, with a mean of 10.48 NM (see Figure 91). Of the complete data set, 848 data points lacked geolocation information and were removed from distance calculations.

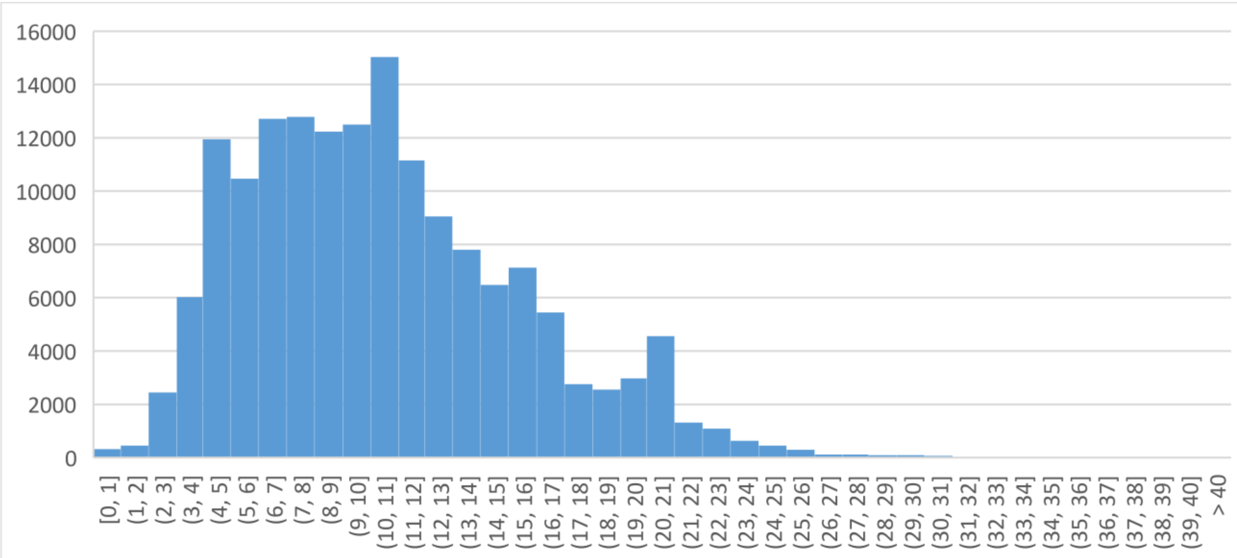


Figure 91. UAS Detections by Range (NM) taken from DFW Airport, August 2018-January 2020.

Of the detected 12,520 unique unmanned aircraft, three model types dominated the data set, including the MavicPro (31.0%), Mavic 2 (25.5%), and MavicAir (10.8%). Approximately 9.8% of the detected unmanned aircraft were unable to be identified. The number of UAS flights were strongly correlated (*r* = .96) with the UAS model population (see Figure 92).

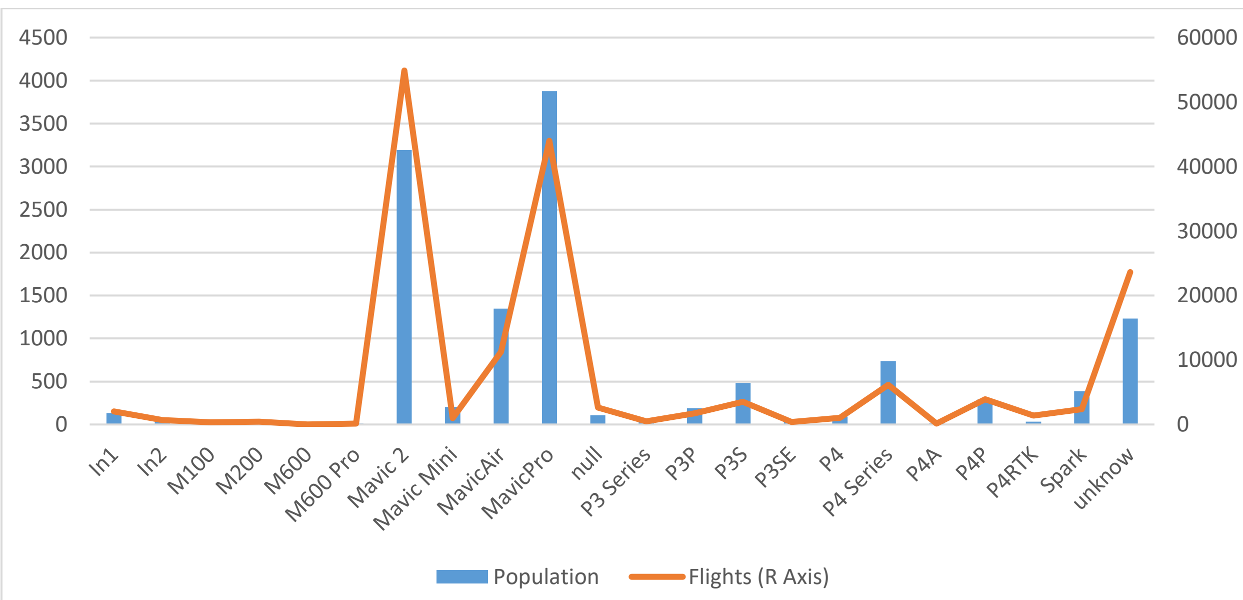


Figure 92. UAS Population by Model with Flight Operations Count taken from DFW Airport, August 2018 - January 2020.

8.3 Operational Findings

The research team observed several characteristics that codify operational behaviors, including when and how UAS are being flown. A summary of these findings is presented below.

8.3.1 Time of Operation

All data within the data set contained detection time information. The mean time of detected UAS flights occurred at 13:58 (local) and at a median time of 14:16 (local). An elevated number of flights were detected on both Saturdays and Sundays in the mid to late afternoon hours (see Figure 93).

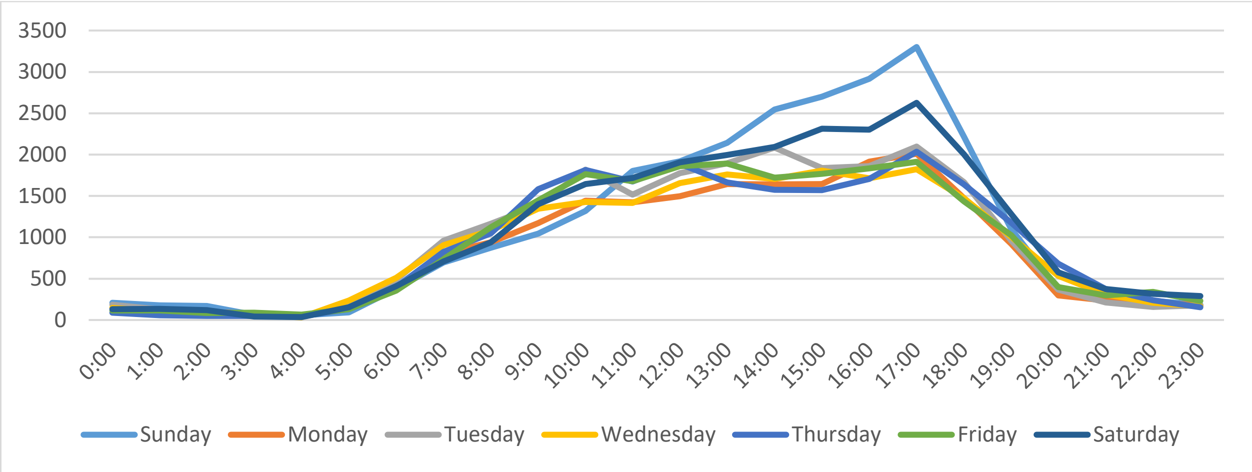


Figure 93. UAS Flight Detections by Time (Local Time) and Day of Week taken from DFW Airport, August 2018-Jan 2020.

While most flights appeared to occur within daylight hours, the research team wanted to further evaluate operator compliance with Part 107.29 provisions. Sunrise, sunset, and civil twilight times were graphically plotted and overlaid with UAS detections for the 2019 portion of the data set (see Figure 94). While the preponderance of operations appears to fall within daylight hours, a sizable quantity of flights falls outside daylight hours. According to the FAA (2020), at least 4,308 Part 107.29 waivers have been issued, authorizing flights for selected operations outside daylight hours. It is not possible to determine what proportion of these waivers were issued for operations occurring within the Dallas-Fort Worth area.

8.3.2 Day of Year

The research team assessed flight activity over time to evaluate operational high and low periods. Convenience sampling data from 2019, flight activity was plotted by date (see Figure 95).

Peak operational dates were identified, indicating disproportionate levels of detected UAS activity. Several peak operational dates corresponded with recognized holidays, which suggest elevated hobbyist activity (see Table 23). Dates with depressed UAS activity levels were also identified (see Table 24).

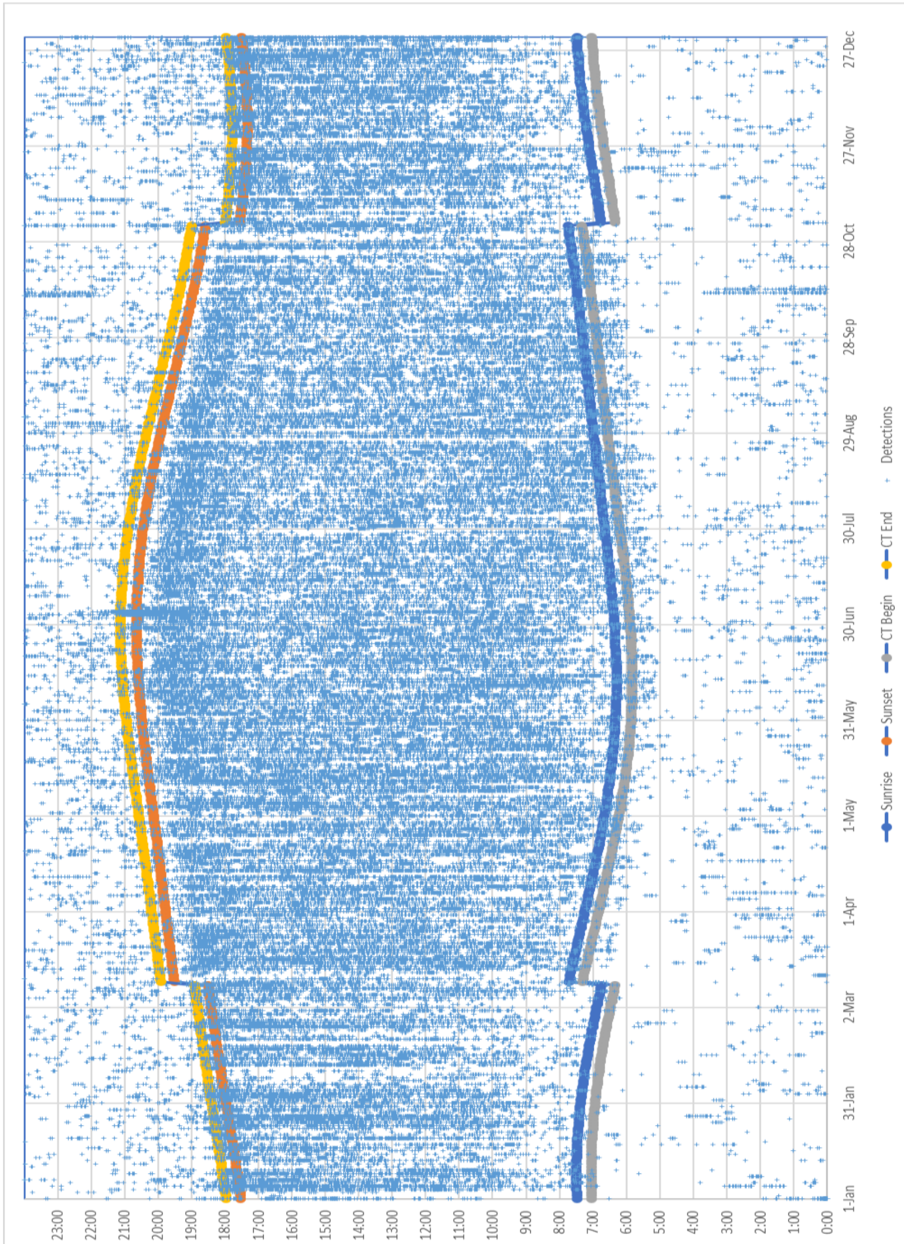


Figure 94. UAS Flight Detections by Time Overlaid with Sunrise, Sunset, & Civil Twilight Times (Local Time), convenience annual sample taken from DFW Airport, January 2019-December 2019.

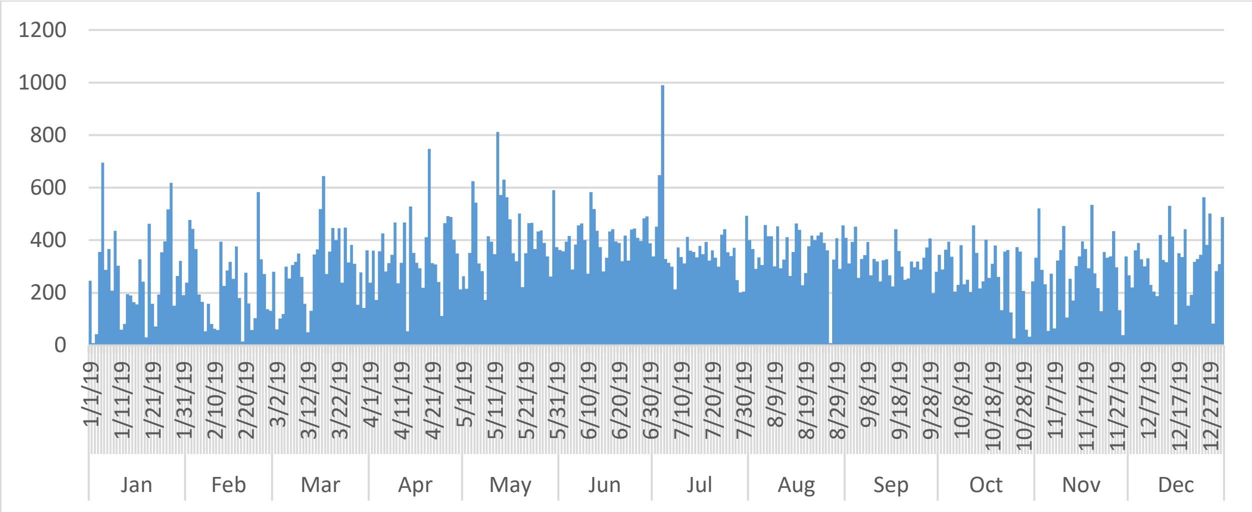


Figure 95: UAS Flights by Day of Year, DFW Airport January 2019-December 2019.

Table 23. UAS Detection Dates with Greater than 600 Flights Per Day (2019).

Date	Day of Week	No.	Occasion
1/5/19	Saturday	695	
1/27/19	Sunday	619	
3/17/19	Sunday	644	St. Patrick's Day
4/20/19	Saturday	747	Easter Weekend
5/4/19	Saturday	624	
5/12/19	Sunday	812	
5/14/19	Tuesday	631	
7/3/19	Wednesday	648	
7/4/19	Thursday	990	Independence Day

Table 24. UAS Detection Dates with Fewer than 50 Flights Per Day (2019).

Date	Day of Week	No.
1/2/19	Wednesday	9
1/3/19	Thursday	42
1/19/19	Saturday	30
2/19/19	Tuesday	14
8/27/19	Tuesday	9
10/25/19	Friday	27
10/30/19	Wednesday	33
11/29/19	Friday	39

8.3.3 Flight Duration

The duration of detected flights tended to be extremely short, with a mean of 76 seconds and a median of 18 seconds. It is notable that among the 162,162 flights, there were 59,006 with a recorded duration of 0 seconds—these have been removed from the data set for analysis purposes. A graphical depiction of flight durations is provided in Figure 96. It is unclear to the research team why UAS flights would be so short, from an operational perspective. One possible explanation is that UAS operators are exercising considerable restraint to avoid overflying the energy capacity of their batteries. The researchers also assess that it may be possible that the AeroScope is not capturing the full extent of flights, due to obstructions in line of sight between the sensor and low-altitude UAS platforms. Additional analysis will have to be performed to validate this suspicion.

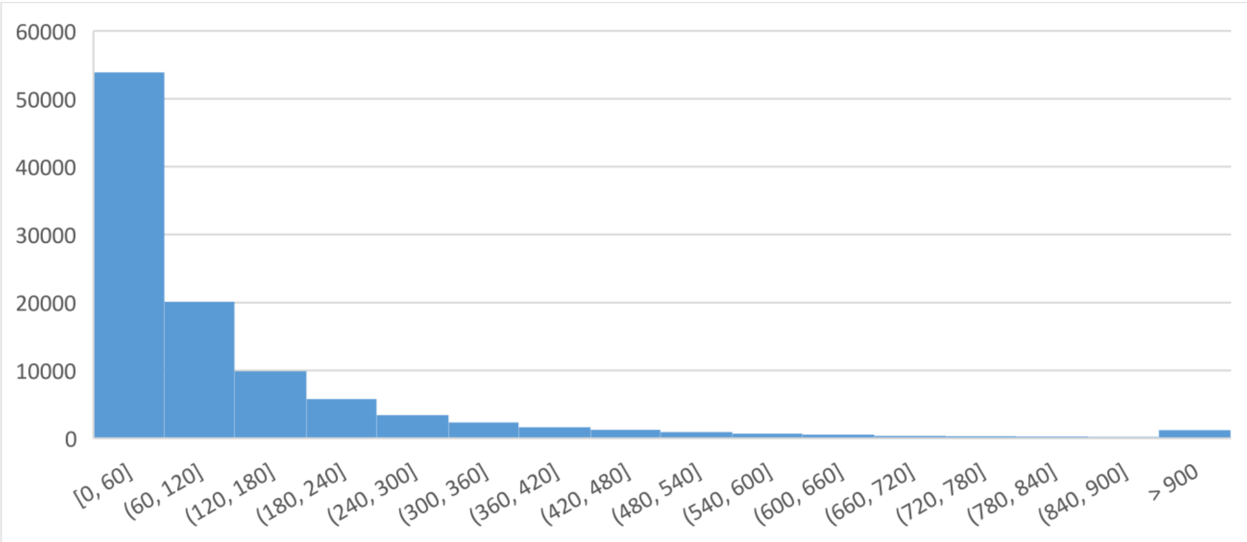


Figure 96. Histogram of UAS Flight Durations in seconds, taken from DFW Airport, August 2018-January 2020.

The data were further distributed to show the flight duration by each platform type (Figure 97). Elevated flight durations were seen in the Phantom 4 product line, as well as the Inspire 2 and MavicPro.

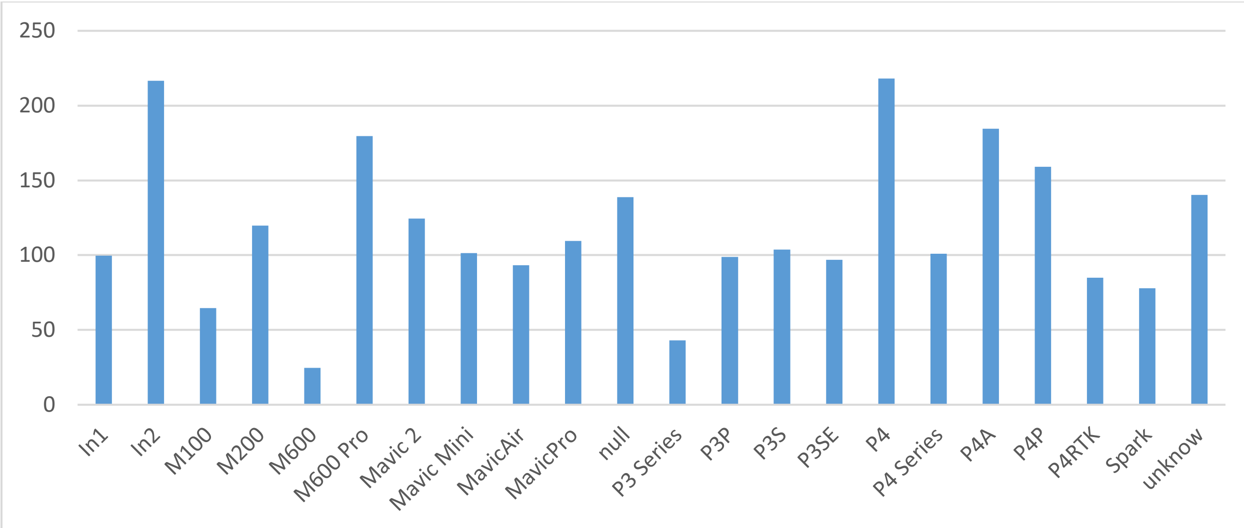


Figure 97. Average flight duration of detected UAS operations in seconds, taken at DFW Airport, August 2018-January 2020.

Figure 98 depicts platform flight durations as a proportion of total platform detections.

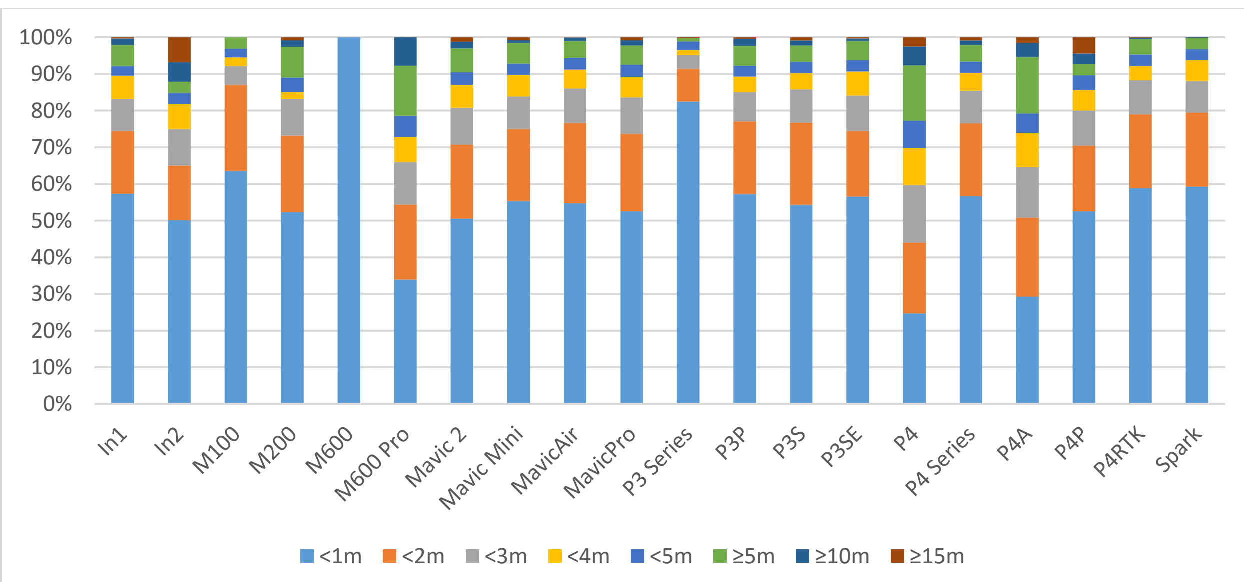


Figure 98. Detected platform flight durations by proportion of total platform detections, taken at DFW Airport August 2018-January 2020.

8.3.4 Altitude

Approximately 94.7% (n = 153,535) of all detected UAS flights occurred below 400 ft AGL. Researchers noted 4,735 UAS flights exceeded 500 feet AGL, with 1,168 of those exceeding 1,000 ft AGL. The distribution of UAS flight altitudes among the detection data set is presented in Figure 99. A geographical presentation of UAS flights detected above 1,000 ft AGL is presented in Figure 100.

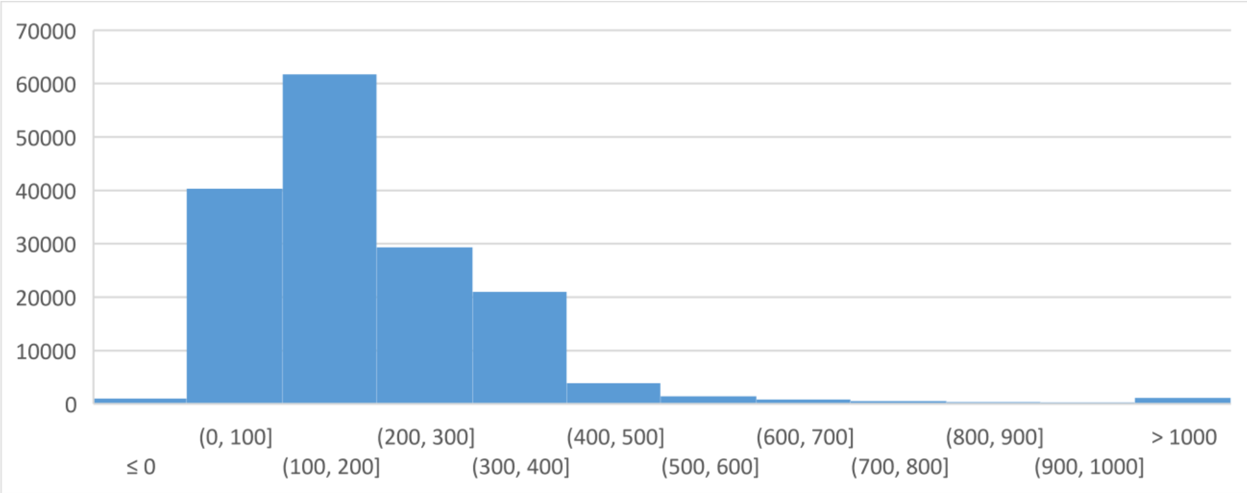


Figure 99. Histogram of UAS Flight Altitudes (ft AGL) taken from DFW Airport, August 2018-January 2020.

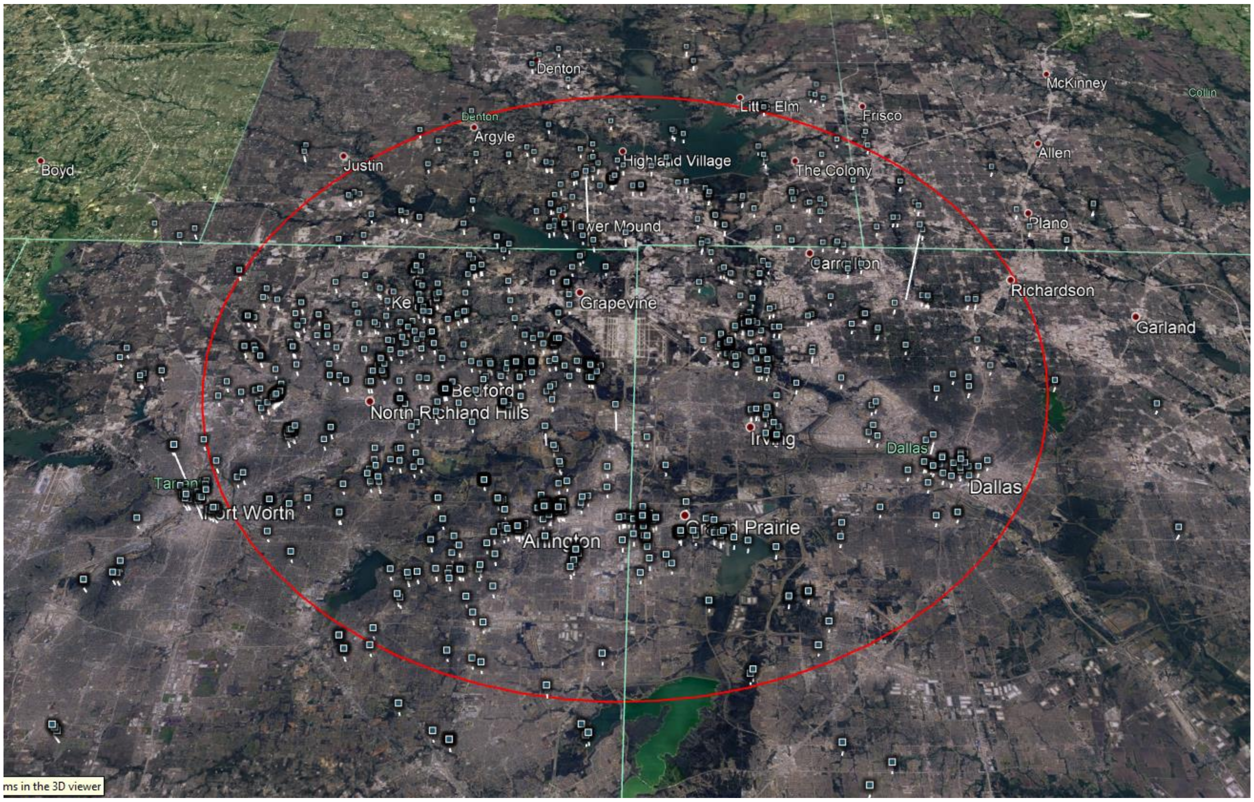


Figure 100. Location of UAS detections exceeding 1,000 ft AGL, taken from DFW Airport, August 2018-January 2020 (red circle has a 15 NM radius perimeter centered at DFW).

While the data set shows that most operators adhere to altitude restrictions, a small portion of the data set indicated gross non-compliance, with three flight detections from three separate DJI MavicPro operators exceeding 21,000 feet AGL.

8.3.5 *Proximity to Aerodromes*

Using geolocation information, the research team assessed each flight's proximity to area airports. DFW encountered 226 UAS flights within .5 NM of the airfield, with some flights occurring on the airfield. GPM encountered eight flights within .5 NM of the field (see Figure 1019). It is notable, however, that authorized UAS operations are performed on the airfield and ramp areas on a regular basis by both DFW Airport and American Airlines. Without additional LAANC or airspace approval data, it is not possible to assess if these flights were authorized.

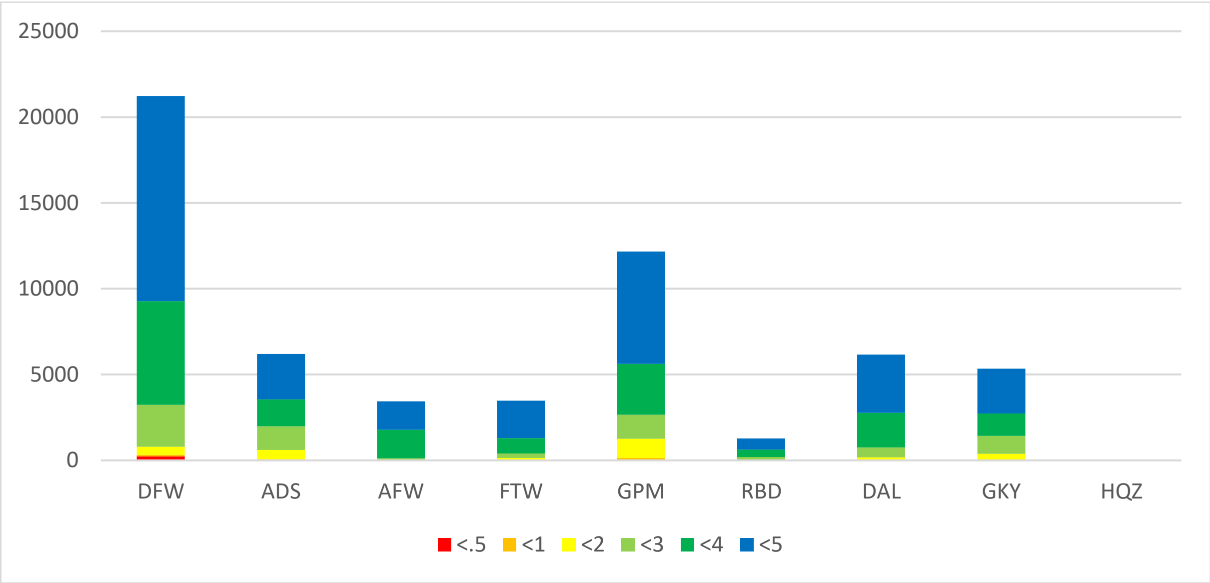


Figure 101. UAS Flight Detections in Proximity to Airports (NM), taken from from sensors deployed at DFW Airport, August 2018-January 2020.

The research team also assessed UAS flight proximity to known heliports. Fifty-one heliports in the Dallas-Fort Worth area were assessed in the initial sample (see Figure 101). A total of 10,919 UAS flights were detected within .5 NM of heliports during the sampling period (see Figure 104).

The research team believes these areas represent a significantly higher risk for NMAC than airports for the following reasons:

- Remote pilots are likely less aware of heliport locations than airport locations
- Helicopter operations tend to operate at lower altitudes, such as those shared with UAS operations

8.3.6 *Registration Data*

Of the complete data set, 99.4% of the platforms (*n* = 12,444) contained geolocation information. The research team assigned each detected platform to a zip code, based on its first detection location. Researchers tallied detected UAS platforms based on assigned zip code and compared them against total number of registrations for each zip code contained in the FAA's UAS Registration Database [2019Q4 release]. The FAA registration database contained 28,885 platforms for all applicable zip codes in the DFW area, including 7,734 registered under Part 107 and 21,151 UAS registered for hobbyist or recreational use. Given these data, AeroScope detections for the area accounted for up to 43.1% of all registered unmanned aircraft in the area. It is notable that the number of unique platforms detected in some areas exceeded the number of

FAA registrations. This may be an indication that not all users are registering their UAS platforms. Alternatively, users may be flying their UAS outside their respective registration area.
Error! Reference source not found. displays area registration data by zip code with overlaid d etected UAS platform census and flight activity. Additional details are provided in Table 25.

Figure 102: Map of DFW vicinity with UAS registrations overlaid upon the map.with airports and heliports assessed in Figure 99.

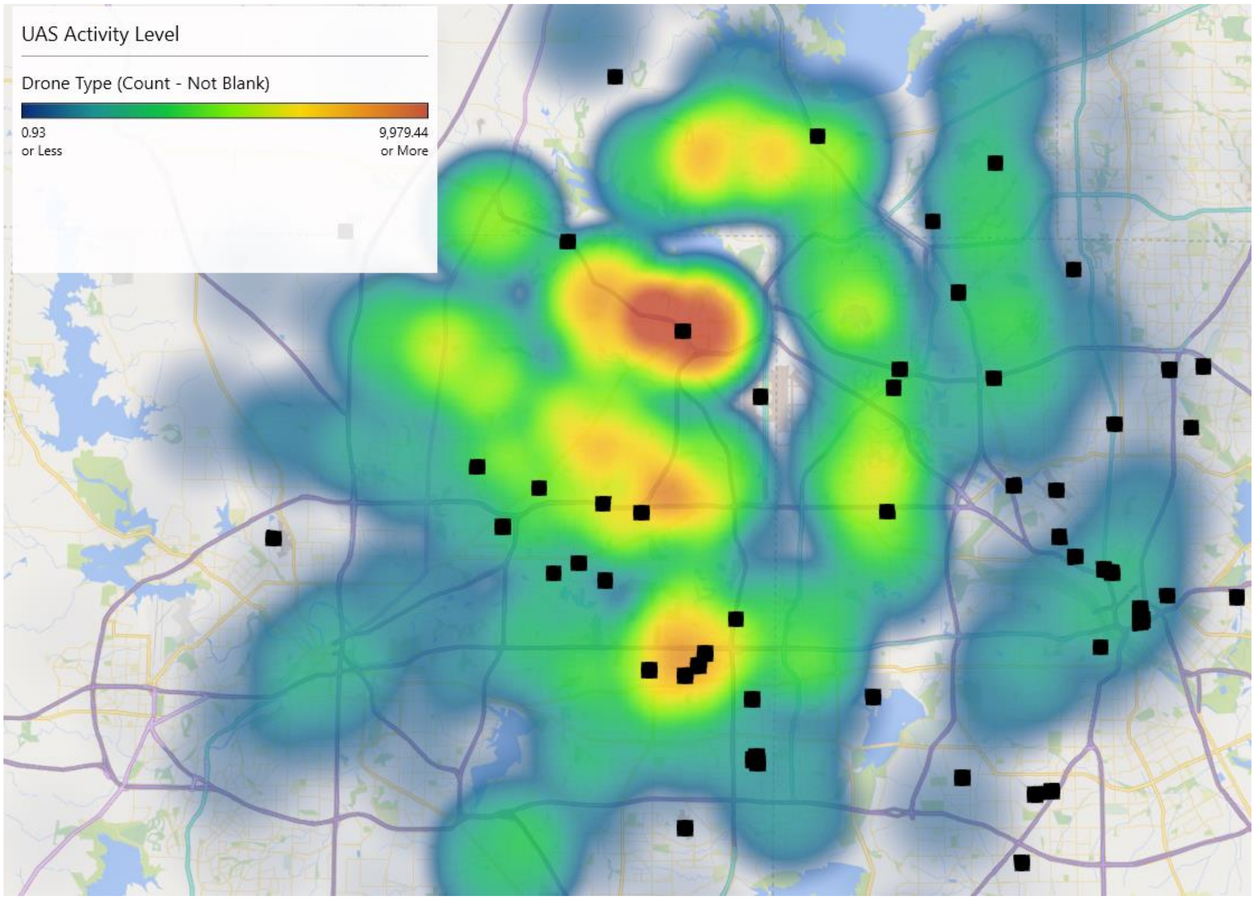


Figure 103. [TOP] Sampled Heliports. [Bottom] UAS Flight Detections in Proximity to Heliports (NM), taken from DFW Airport, August 2018-January 2020.

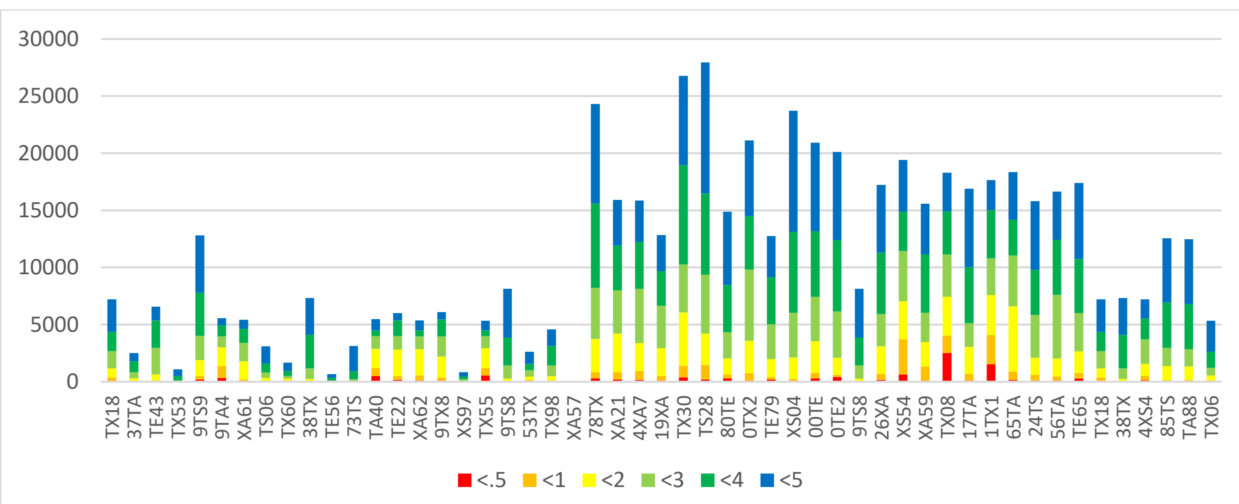


Figure 104. UAS Flight Detections in Proximity to Heliports (NM), taken from DFW Airport, August 2018-January 2020.

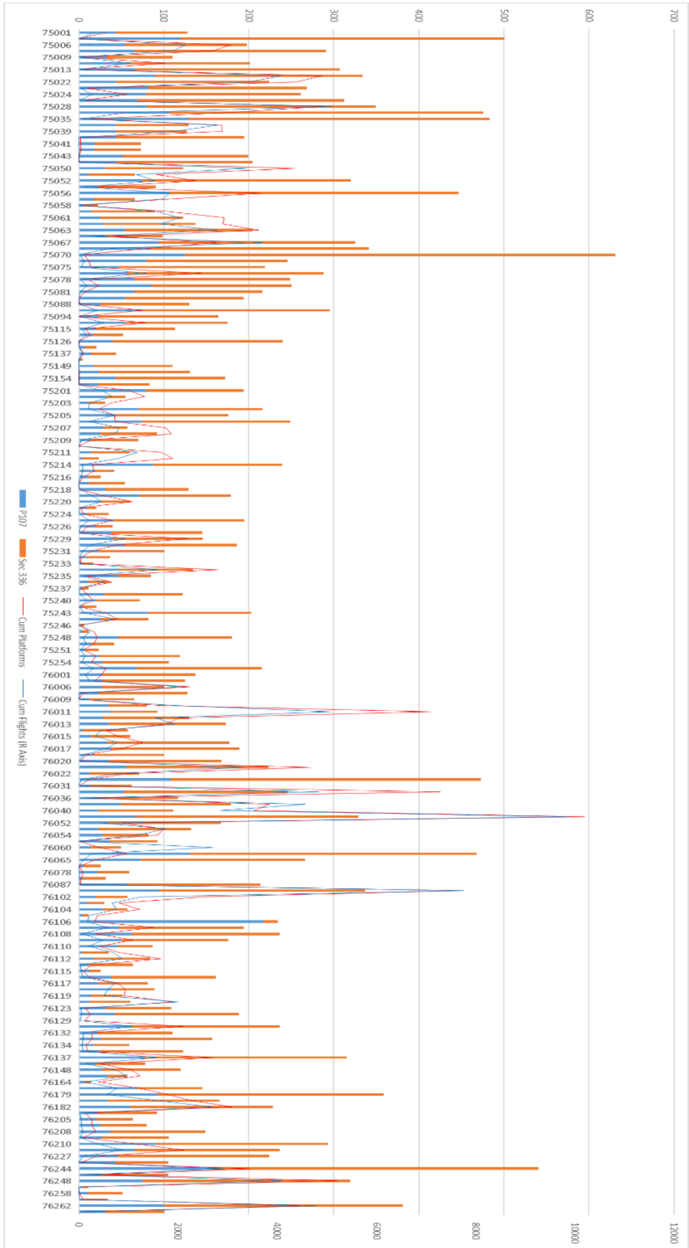


Figure 105. Cumulative UAS Serial Numbers Detected by Zip Code, taken from DFW Airport, August 2018-January 2020.

Table 25. Detected UAS Serial Numbers by Zip Code Compared to UAS Registration Database.

Zip Code	Detected Platforms	P107 Registration	Sec 336 Registrations	Serial# Detection / Registration Ratio
75001	31	43	85	24.2%
75002	1	119	382	0.2%
75006	179	54	144	90.4%
75007	157	65	226	54.0%
75009	2	33	77	1.8%
75010	102	54	147	50.7%
75013	2	67	240	0.7%
75019	286	89	245	85.6%
75022	256	44	180	**114.3%**
75023	10	82	186	3.7%
75024	57	79	182	21.8%
75025	7	69	243	2.2%
75028	289	80	269	82.8%
75034	173	106	370	36.3%
75035	13	129	354	2.7%
75038	168	43	86	**130.2%**
75039	169	44	83	**133.1%**
75040	2	44	151	1.0%
75041	2	19	54	2.7%
75042	3	18	55	4.1%
75043	1	51	148	0.5%
75044	0	45	159	0.0%
75050	254	31	92	**206.5%**
75051	92	12	54	**139.4%**
75052	138	74	246	43.1%
75054	23	22	69	25.3%
75056	214	107	340	47.9%
75057	108	18	48	**163.6%**
75058	1	6	17	4.3%
75060	105	15	75	**116.7%**
75061	171	25	98	**139.0%**
75062	170	30	107	**124.1%**
75063	212	54	150	**103.9%**
75065	39	31	68	39.4%
75067	162	94	231	49.8%
75068	81	85	256	23.8%
75070	6	125	506	1.0%
75074	12	79	167	4.9%
75075	14	48	171	6.4%
75077	144	57	231	50.0%
75078	11	65	184	4.4%
75080	24	86	164	9.6%
75081	8	65	151	3.7%
75082	1	54	140	0.5%
75088	1	25	105	0.8%

75093	76	74	221	25.8%
75094	0	23	141	0.0%
75104	79	55	120	45.1%
75115	8	21	92	7.1%
75116	14	16	36	26.9%
75126	1	40	200	0.4%
75134	1	7	14	4.8%
75137	6	14	30	13.6%
75141	1	3	2	20.0%
75149	0	18	92	0.0%
75150	1	24	107	0.8%
75154	1	43	129	0.6%
75167	1	23	60	1.2%
75201	59	78	116	30.4%
75202	78	32	23	**141.8%**
75203	38	11	20	**122.6%**
75204	24	70	146	11.1%
75205	42	43	133	23.9%
75206	43	74	175	17.3%
75207	103	29	28	**180.7%**
75208	109	25	67	**118.5%**
75209	16	14	56	22.9%
75210	0	0	2	0.0%
75211	97	14	46	**161.7%**
75212	111	4	20	**462.5%**
75214	16	88	151	6.7%
75215	18	19	23	42.9%
75216	5	11	15	19.2%
75217	0	12	42	0.0%
75218	1	31	98	0.8%
75219	28	72	107	15.6%
75220	63	25	35	**105.0%**
75223	2	9	12	9.5%
75224	6	10	25	17.1%
75225	39	41	154	20.0%
75226	10	20	20	25.0%
75228	3	39	106	2.1%
75229	128	40	106	87.7%
75230	46	54	132	24.7%
75231	15	23	78	14.9%
75232	3	9	28	8.1%
75233	2	4	13	11.8%
75234	164	48	86	**122.4%**
75235	10	47	38	11.8%
75236	39	11	24	**111.4%**
75237	2	3	8	18.2%
75238	10	30	92	8.2%
75240	17	20	52	23.6%
75241	1	4	17	4.8%

75243	32	81	122	15.8%
75244	46	26	56	56.1%
75246	0	2	5	0.0%
75247	18	4	7	**163.6%**
75248	22	46	134	12.2%
75249	18	15	27	42.9%
75251	6	8	16	25.0%
75252	20	24	95	16.8%
75254	15	28	78	14.2%
75287	32	68	147	14.9%
76001	27	28	109	19.7%
76002	19	29	96	15.2%
76006	132	27	74	**130.7%**
76008	4	24	104	3.1%
76009	1	12	53	1.5%
76010	95	35	45	**118.8%**
76011	415	37	56	**446.2%**
76012	119	29	101	91.5%
76013	102	36	137	59.0%
76014	33	5	53	56.9%
76015	46	14	47	75.4%
76016	76	34	143	42.9%
76017	50	39	150	26.5%
76018	8	18	82	8.0%
76020	3	36	132	1.8%
76021	273	56	167	**122.4%**
76022	57	13	58	80.3%
76028	13	108	365	2.7%
76031	1	13	49	1.6%
76034	425	53	193	**172.8%**
76036	11	21	96	9.4%
76039	224	50	129	**125.1%**
76040	206	23	88	**185.6%**
76051	595	67	262	**180.9%**
76052	50	34	133	29.9%
76053	100	23	109	75.8%
76054	93	29	53	**113.4%**
76058	0	36	57	0.0%
76060	25	14	36	50.0%
76063	57	131	337	12.2%
76065	19	73	193	7.1%
76071	1	6	20	3.8%
76078	5	22	37	8.5%
76084	3	5	27	9.4%
76087	2	57	157	0.9%
76092	449	95	242	**133.2%**
76102	146	20	37	**256.1%**
76103	47	10	20	**156.7%**
76104	72	28	29	**126.3%**

76105	22	5	6	**200.0%**
76106	19	217	17	8.1%
76107	89	48	146	45.9%
76108	20	62	174	8.5%
76109	64	50	126	36.4%
76110	25	46	41	28.7%
76111	47	4	31	**134.3%**
76112	97	17	67	**115.5%**
76114	16	12	52	25.0%
76115	5	13	13	19.2%
76116	12	39	122	7.5%
76117	46	23	58	56.8%
76118	55	39	50	61.8%
76119	53	15	36	**103.9%**
76120	111	13	48	**182.0%**
76123	8	32	77	7.3%
76126	14	42	146	7.4%
76129	7	0	0	
76131	123	61	175	52.1%
76132	15	22	88	13.6%
76133	16	26	131	10.2%
76134	9	17	42	15.3%
76135	10	25	98	8.1%
76137	159	75	240	50.5%
76140	25	19	59	32.1%
76148	62	27	93	51.7%
76155	73	34	23	**128.1%**
76164	23	7	7	**164.3%**
76177	71	69	76	49.0%
76179	104	93	266	29.0%
76180	134	34	132	80.7%
76182	180	61	167	78.9%
76201	7	23	69	7.6%
76205	16	21	43	25.0%
76207	15	26	54	18.8%
76208	20	37	112	13.4%
76209	5	27	79	4.7%
76210	67	91	202	22.9%
76226	124	66	170	52.5%
76227	20	46	178	8.9%
76234	3	43	62	2.9%
76244	203	155	386	37.5%
76247	27	24	81	25.7%
76248	304	75	244	95.3%
76252	0	4	7	0.0%
76258	1	11	40	2.0%
76259	6	5	29	17.6%
76262	260	100	281	68.2%
76266	1	31	70	1.0%

8.3.7 Growth Trends

Using the historical DFW detection data, the research team attempted to project future industry growth patterns. The research team evaluated the data set for initial detections of new UAS serial numbers, a possible growth indicator. Similarly, the research team assessed the data set for UAS serial numbers which were no longer active, a possible consolidation indicator. The results are presented in Figure 106. Over the 18-month sampling period, the data shows a marked decline in new entrants and an accelerating rate of platforms no longer in active use. September 2018 showed a net gain of 659 platforms, while December 2019 showed a net loss of 302 platforms. It is important to note that this change was only measured in the DFW region, which may not necessarily represent UAS operational activity in other areas of the country.

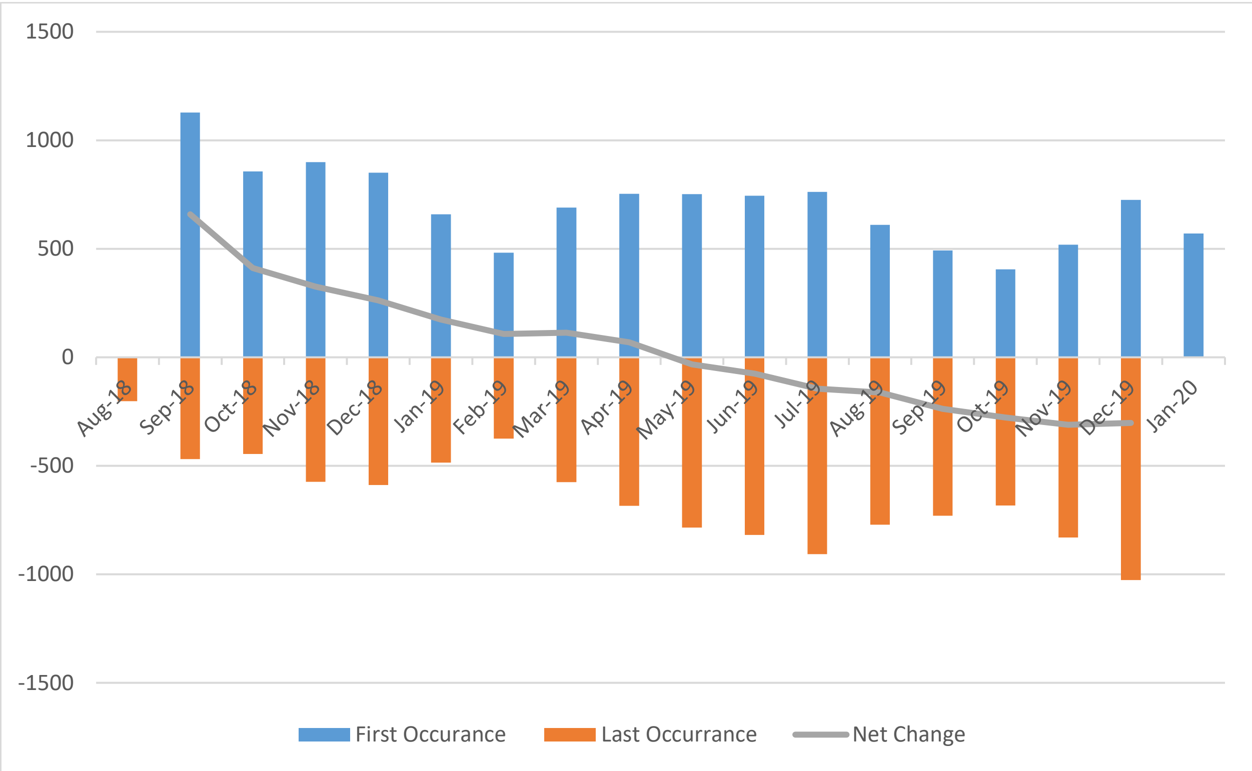


Figure 106. UAS detections by platform serial number, taken at DFW Airport August 2018-January 2020.

A summary of new entrants by platform is provided in Figure 107.

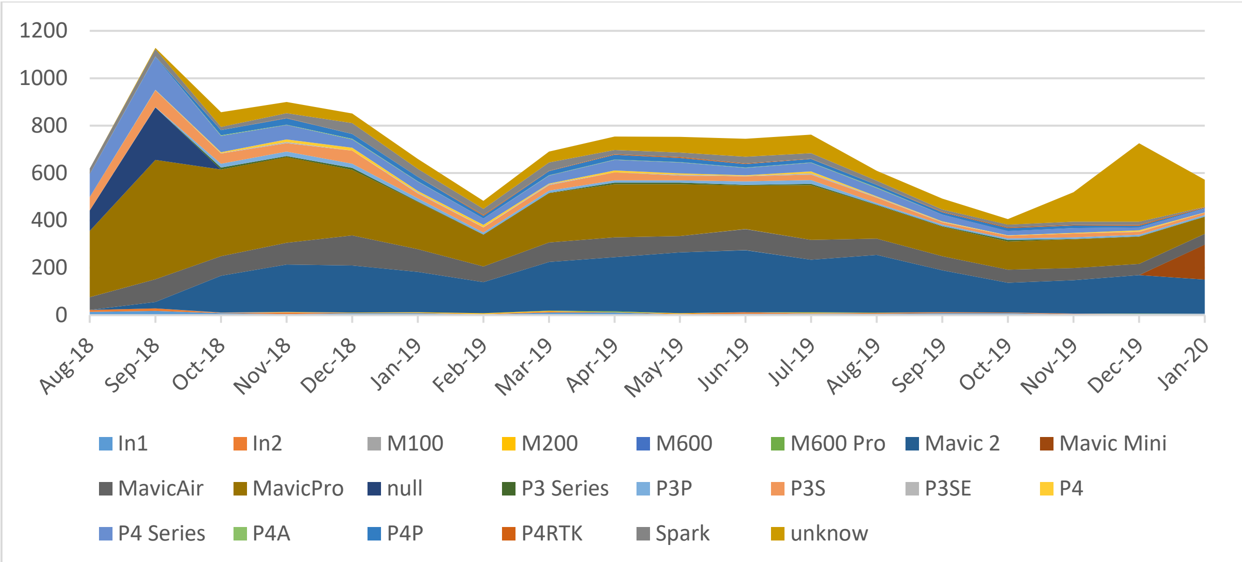


Figure 107. UAS detections by UAS model and serial number, taken at DFW Airport August 2018-January 2020.

The research team have a possible explanation for the increased consolidation. Based on UAS detection data, the lifecycle of a UAS may be much shorter than originally anticipated. The research team evaluated the data set for the number of non-consecutive months of utilization of each UAS serial number and discovered that 58.3% of UAS (*n* = 7,299) are only used during a *single month*. Only 17.4% of platforms were detected operating during a second, non-consecutive month. By the third non-consecutive month, only 9.0% of platforms remained active. See Figure 108.

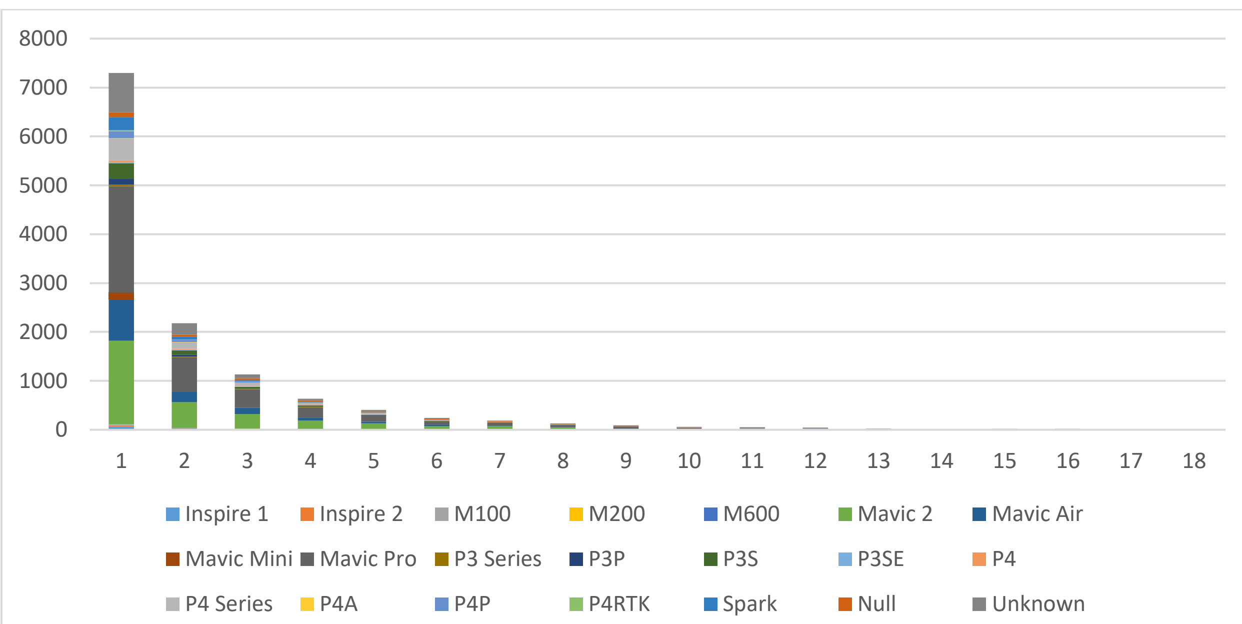


Figure 108. Months of non-consecutive UAS platform utilization by model serial number, taken at DFW Airport August 2018-January 2020.

In a separate analysis, the research team counted the number of total flights flown by UAS serial number (see Figure 109). At least 45.5% of UAS (*n* = 5,696) were *only flown five times*. Nearly 83.5% of platforms

(n = 10,451) had performed *less than 20 flights* until they were no longer actively detected. The researchers believe this finding may suggest that the majority of UAS are operated at a high frequency for a short span of time, and likely for hobbyist or recreational purposes. Once the novelty of the platform has worn off, operators relegate the UAS to storage and only rarely fly again.

8.3.8 Conclusions

Use of the Aeroscope system provides vital empirical data highlighting the status of low-altitude UAS activity surrounding a major U.S. airport. Data suggests high levels of UAS utilization, primarily during daylight hours, with slightly elevated levels on weekends. The mean flight activity level was measured at a mean of 282 flights per day, as well as 161 daily UAS activations (the UAS was turned on, but flight telemetry was not recorded). Generally, flight activity remained stable throughout the year, with spikes during selected holidays and weekends, and troughs at the beginning of the calendar year and selected weekdays. Flight operations were characterized by a strong preference for modern UAS platforms, including the Mavic Pro, Mavic 2, and Mavic Air. The mean flight duration remained short, at just over a minute of recorded flight time. For all UAS activity, 94.7% occurred below 400 feet AGL; however, at least 1,168 UAS flights were detected in excess of 1,000 feet AGL. This finding is somewhat concerning, given the density of manned traffic in sample location. The majority of UAS flights were clear of the immediate proximity of airports, with DFW encountering 226 UAS flights within .5 NM of the airfield. Of the 51 sampled heliports, at least 10,919 UAS flights were recorded within .5 NM. The research team recorded a cumulative 12,444 separate DJI platforms in the sample area. Based on available UAS registration data, this accounted for 43.1% of all registered platforms. It is notable that the number of unique platforms detected in some areas exceeded number of FAA registrations in the area. This may be an indication that not all users are registering their UAS platforms. Alternatively, users may be flying their UAS outside their respective registration area. Based on an assessment of individual serial number tracking, the research team assessed a general downtrend in detection of new UAS serial numbers vs. the number of previously detected serial numbers that are no longer actively flying. The net loss of platforms is estimated at approximately 58 UAS platforms per month. This may indicate possible industry consolidation or, alternatively, a move away from DJI products. Additional analysis data suggests the initial usage of UAS is limited, with 58.3% of UAS serial numbers only actively detected during a single 30-day period. Based on flight counts by unique serial number, at least 45.5% of UAS were flown five times or less before no longer being actively detected. This finding may indicate recreational activity, which demonstrates high levels of initial use, but low longevity.

These data may suggest the following conditions:

- Preferred platforms are generally smaller in size, which are likely to be difficult to spot by pilots
- Operations data indicates there may be sizable pockets of unregistered UAS in select areas
- Gradually declining number of actively operating UAS platforms
- Most UAS operations remain clear of airports, but may be inadvertently operating near private heliports
- Generally compliant operations, with a small number of outliers that may pose elevated hazards to aviation
- High levels of recreational platform use; generally, these platforms see only high-frequency initial use

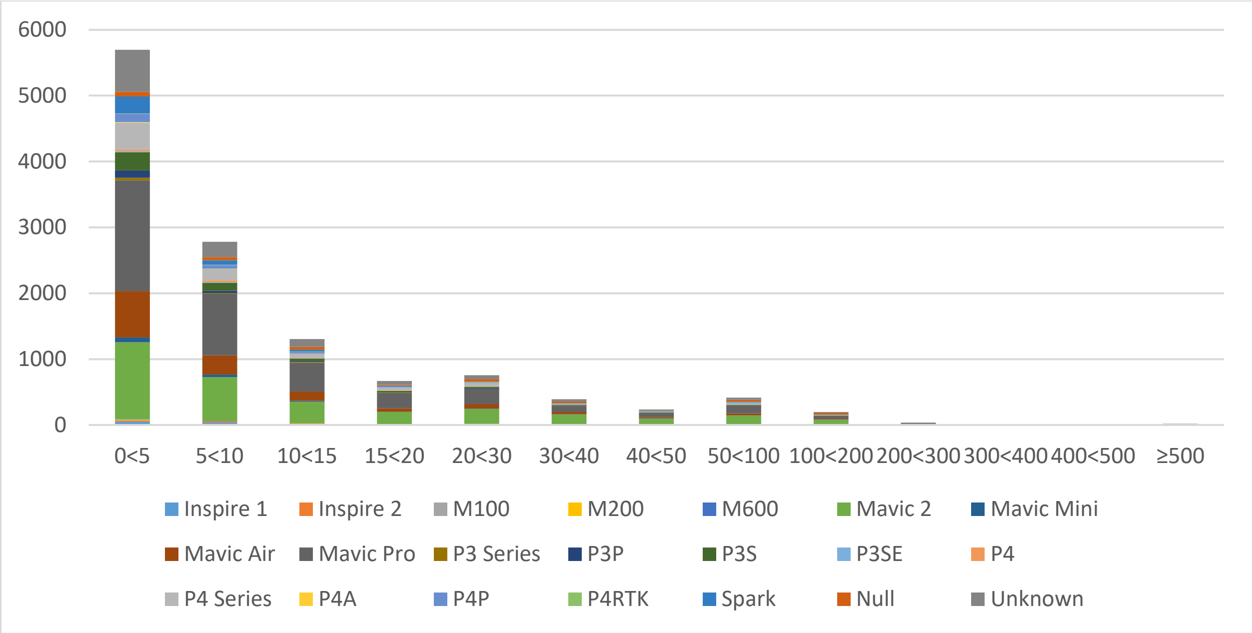


Figure 109. Number of cumulative detected flights by UAS model serial number, taken at DFW Airport August 2018-January 2020.

8.4 UAS Sighting Reports

The research team conducted an in-depth analysis of UAS sightings by pilots, controllers and other stakeholders that occurred within the vicinity of Dallas-Fort Worth International Airport and were reported to the Federal Aviation Administration. The sample included 41 reports of UAS encounters or other potentially hazardous UAS activity that occurred between 3 December, 2018 and 15 August, 2019.

For each sighting report, the team extracted historical telemetry data for detected DJI UAS for the timeframe of each reported UAS sighting from the Aeroscope system deployed on the DFW airfield. Additionally, Traffic Flow Management System (TFMS) data received from both the Federal Aviation Administration and Embry-Riddle Aeronautical University's (ERAU) Next-Generation Advanced Research (NEAR) Lab for the same timeframes provided position updates for manned traffic in the vicinity. Both the UAS detection and TFMS data sets was parsed, formatted, and translated into a keyhole markup language (KML) for analysis in Google Earth Pro and other geographical information system software.

Using UAS sighting report narratives and supplemental data, the research team attempted to correlate the UAS detection and aircraft traffic data to validate sighting report information.

In most cases, sighting reports could not be positively validated for the following reasons:

- No UAS was detected in the vicinity of the reported UAS sighting location
- Sighting report location was out of range of the DJI Aeroscope sensor or available TFMS telemetry data
- UAS sighting report narrative did not provide adequate detail to pinpoint position of UAS
- Multiple, simultaneous UAS operations were detected that could have met the sighting criteria

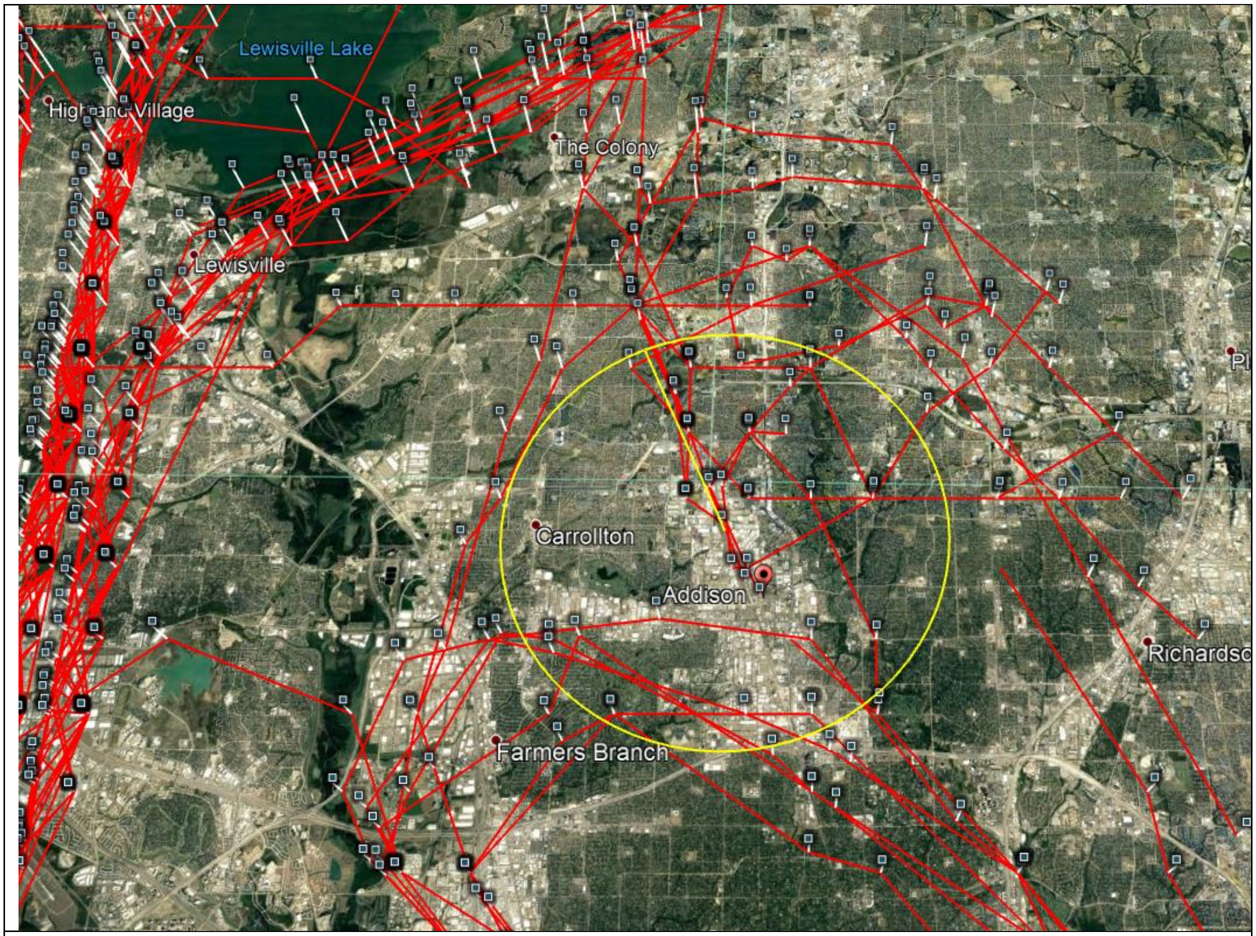
8.4.1 Limitations & Assumptions

This analysis was subject to several notable assumptions and limitations:

- The team assumed that documented sighting reports included generally accurate time and location information.
- UAS detection capability was limited to DJI-manufactured UAS. It is possible that reported encounters or sightings involved UAS platforms not manufactured by DJI, which would preclude detection by the Aeroscope system.
- Is possible that UAS sighting reports included objects that were not unmanned aircraft. According to a Government Accountability Office (2018) report, "the reliability of many of the [sighting] reports is questionable; FAA explained that this is because pilots can have difficulty positively identifying objects as small as UAS, given their small size, their distance from the observed position, the speeds at which a manned aircraft and a UAS are operating, or the various factors competing for the pilot's attention" (pp. 11-12). In an intensive study of UAS sighting reports, the Academy of Model Aeronautics (2017) further highlighted sighting report limitations, indicating that UAS sighting reports may inadvertently contain reports of other unidentified flying objects such as blimps, balloons, birds, or kites (Academy of Model Aeronautics, 2017). In such cases of misidentification, no UAS detection data would be available in the data set.
- A UAS sighting report does not by itself indicate non-compliance on behalf of the UAS operator. According to an Unmanned Aircraft Safety Team (UAST) (2017) report, "A [sighting] report does not necessarily involve the violation of regulations or error by the air traffic control system, nor does it necessarily represent an unsafe condition" (p. 5).
- Traffic Flow Management System data is collected at a relatively low sample rate, which may result in decreased geolocation fidelity for manned aircraft.

8.4.2 Findings

Of the 41 analyzed sighting reports, 50% were able to be correlated to UAS detection data; 25% could not be correlated due to a lack of UAS detection data in the sighting area; and 25% could not be correlated because the sighting location was outside the Aeroscope coverage area. Representative findings of both aircraft and UAS telemetry are presented in the figures below, with the corresponding sighting report narrative.

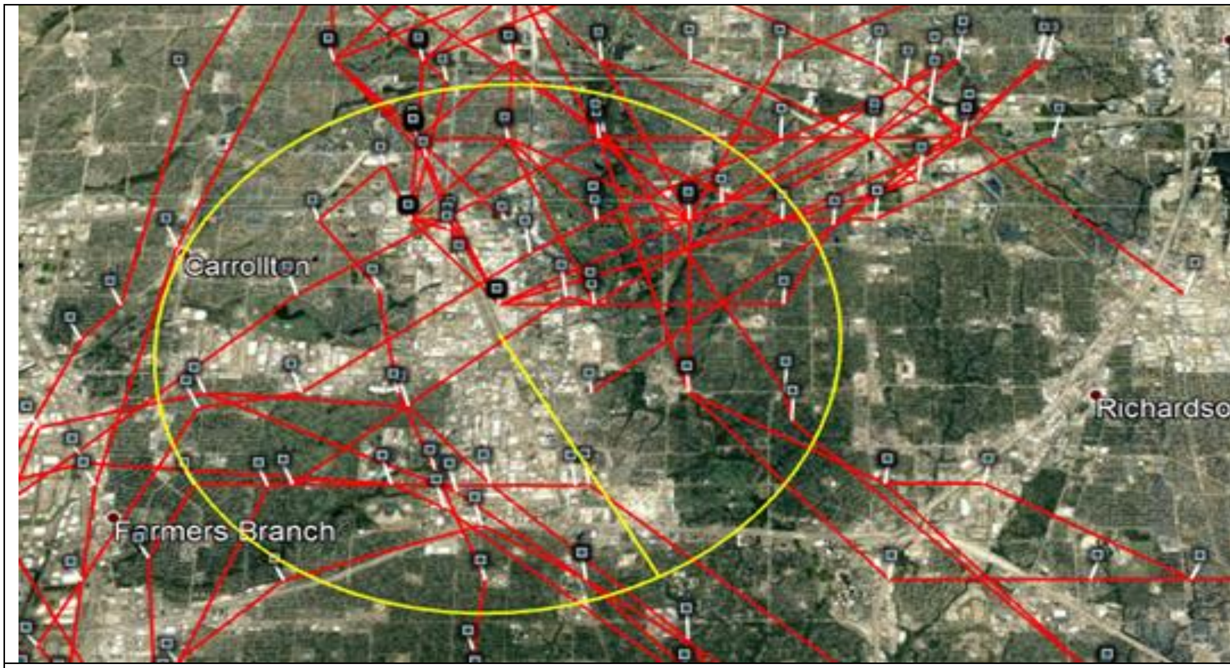


PRELIM INFO FROM FAA OPS: DALLAS, TX/UAS INCIDENT/1730C/C-ROC ADVISED BEECH BE36 REPORTED YELLOW AND BLACK FIXED WING UAS 300 FEET OFF LEFT WING WHILE SSE BOUND AT UNKN ALTITUDE 3 MILE FINAL RWY 15. NO EVASIVE ACTION TAKEN. LOCAL ADDISON PD NOTIFIED.

UAS MOR Alert for ADS
Number: ADS-M-2019/04/22-0003
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: Apr 22, 2019 - 2230Z
A/C: (BE36)

Summary: PILOT REPORTED YELLOW AND BLACK DRONE 300FT OFF HIS LEFT WING ON FINAL.

Figure 110. Sample UAS sighting report telemetry and accompanying sighting report (unable to be correlated due to lack of detection data). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. In this case no UAS activity was detected within the vicinity of the final approach into Addison (ADS) during the reported timeframe.

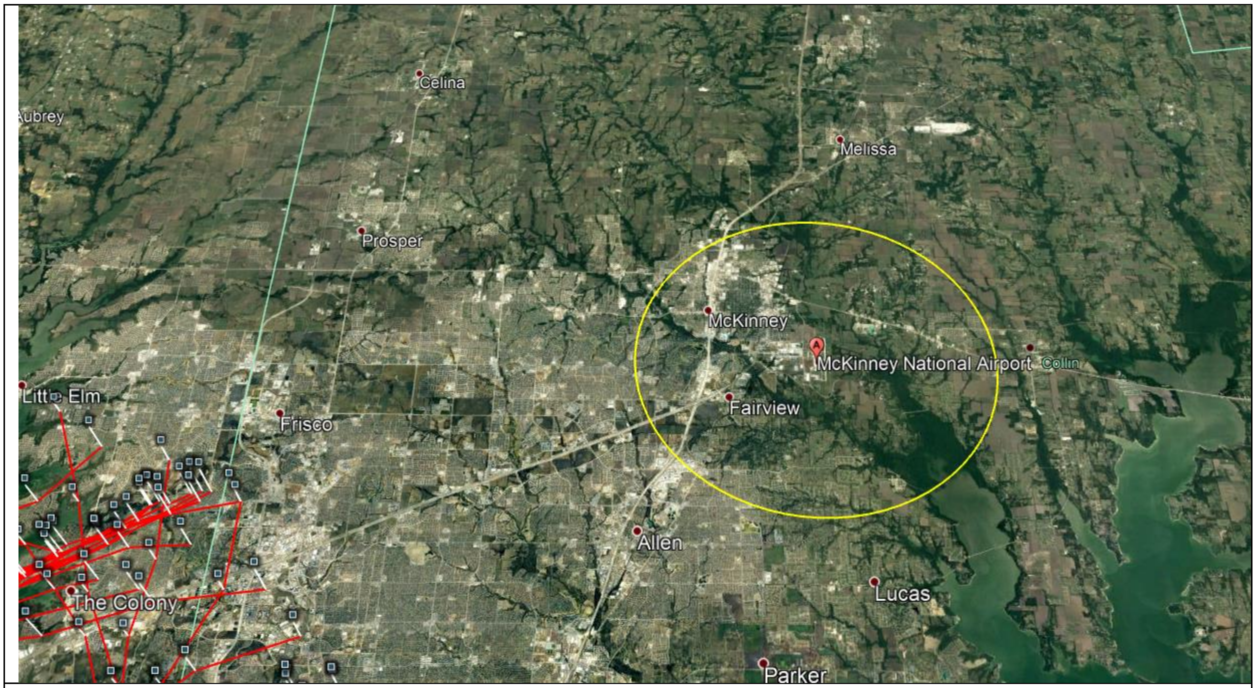


PRELIM INFO FROM FAA OPS: DALLAS, TX/UAS INCIDENT/1911C/DFW TRACON ADVISED LJ40 REPORTED A GRAY AND BLACK QUAD COPTER 500 FEET OVERHEAD, WHILE WESTBOUND, DESCENDING OUT OF 3500 FEET, 3 SE ADDISON ARPT. NO EVASIVE ACTION TAKEN. DFW DPS NOTIFIED.

UAS MOR Alert for D10
Number: D10-M-2019/06/04-0006
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: Jun 4, 2019 - 2335Z
A/C: (LJ40)

Summary: AT 2335 UTC, 3 MILES SOUTHEAST OF ADS ARPT, LJ40 W-BOUND IFR ARRIVAL TO DAL ARPT, DESCENDING OUT OF 3500 FEET REPORTED A UAS 500 FEET OVERHEAD. NO EVASIVE ACTION TAKEN. DFW DPS/DEN NOTIFIED

Figure 111. Sample UAS sighting report telemetry and accompanying sighting report (unable to be correlated due to lack of detection data). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. No UAS activity detected in the vicinity of 3 NM southeast of Addison (ADS) airport.

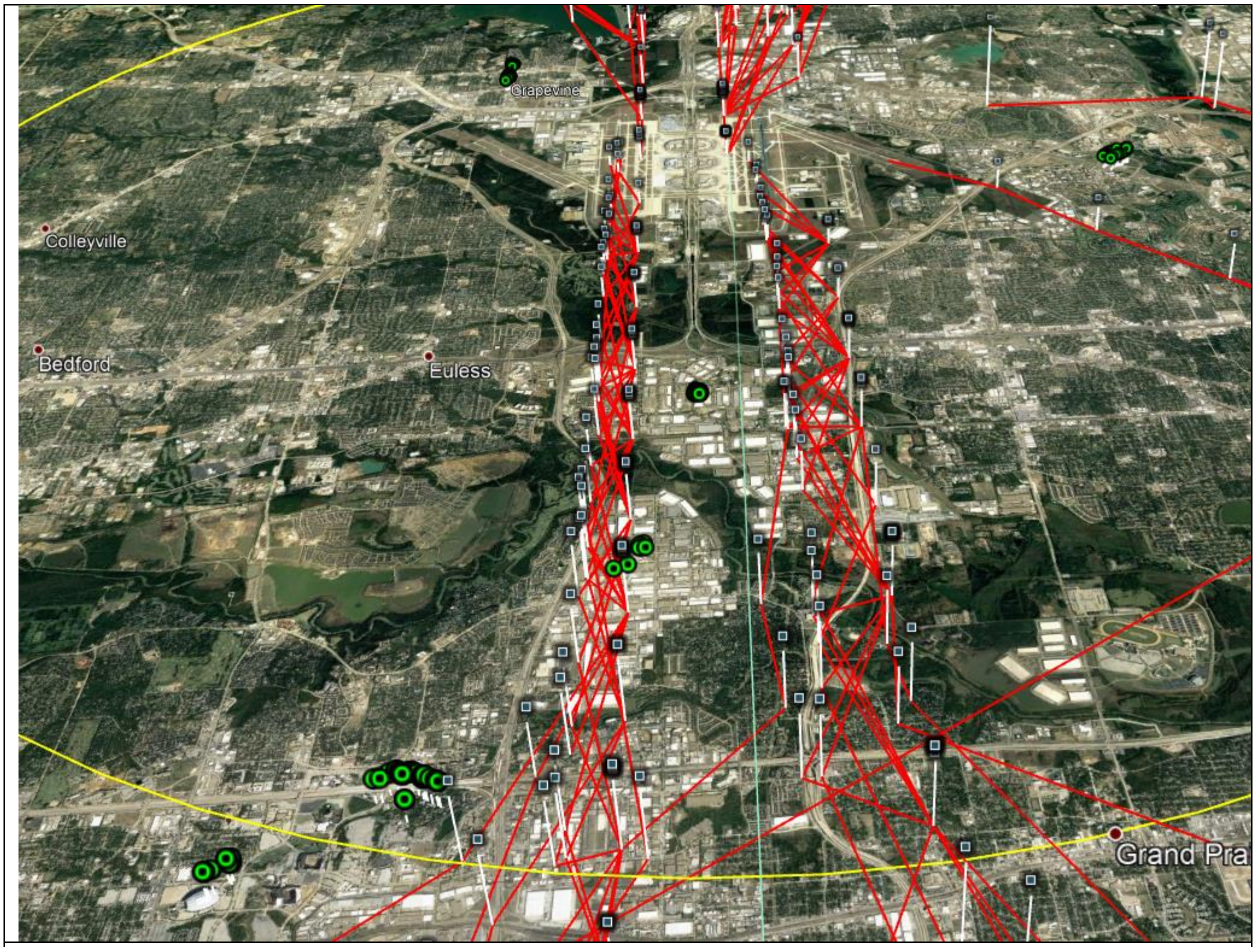


PRELIM INFO FROM FAA OPS: DALLAS, TX/UAS INCIDENT/1449C/DALLAS TRACON ADVISED , BOMBARDIER CL60,REPORTED A UAS FROM THE RIGHT SIDE AT 4,500 FEET WHILE SW BOUND AT 4,000 FEET 4 SW MCKINNEY NATIONAL ARPT. NO EVASIVE ACTION TAKEN. DFW DPS NOTIFIED AT

UAS MOR Alert for D10
Number: D10-M-2019/08/06-0003
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: Aug 6, 2019 - 1949Z
A/C: (CL60)

Summary: AT 1949 UTC, 4 MILES SOUTHWEST OF THE TKI ARPT,CL60 SW-BOUND IFR DAL ARRIVAL AT 4000 FEET, REPORTED A DRONE OFF THE RIGHT SIDE OF THE ACFT, DRONE AT 4500 FEET. NO EVASIVE ACTION TAKEN. DFW DPS/DEN NOTIFIED.

Figure 112. Sample UAS sighting report telemetry and accompanying sighting report (unable to be correlated / out of range). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. McKinney National Airport out of range of both UAS detection data and TFMS traffic data request.

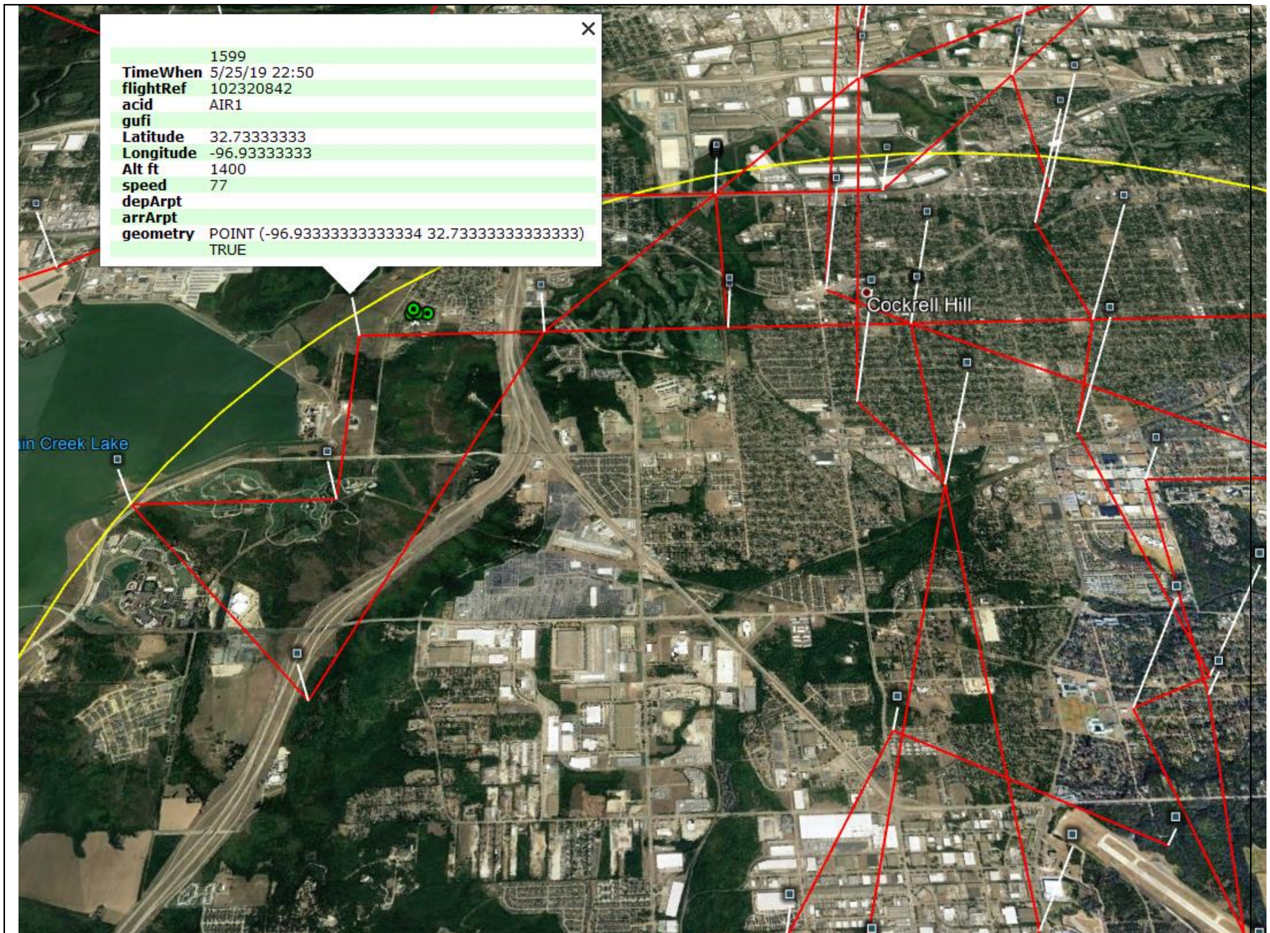


PRELIM INFO FROM FAA OPS: DALLAS-FORT WORTH, TX/UAS INCIDENT/1232C/DFW ATCT ADVISED A321, REPORTED A WHITE QUAD COPTER 200 FEET BELOW ACFT WHILE ON VISUAL APPROACH TO RUNWAY 35C 8 S DFW. NO EVASIVE ACTION REPORTED. DFW DPS NOTIFIED.

UAS MOR Alert for D10
Number: D10-M-2019/05/12-0004
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: May 12, 2019 - 1732Z
A/C: (A321)

Summary: A321 on a visual approach to DFW RWY 35C reported a white quad copter 8 miles south of the airport 200 feet below them. A321 did not take any evasive action.

Figure 113. Sample UAS sighting report telemetry and accompanying sighting report (correlated). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. In this case, multiple UAS activities were occurring along the approach path, with a maximum altitude of approximately 149m (488 ft AGL).

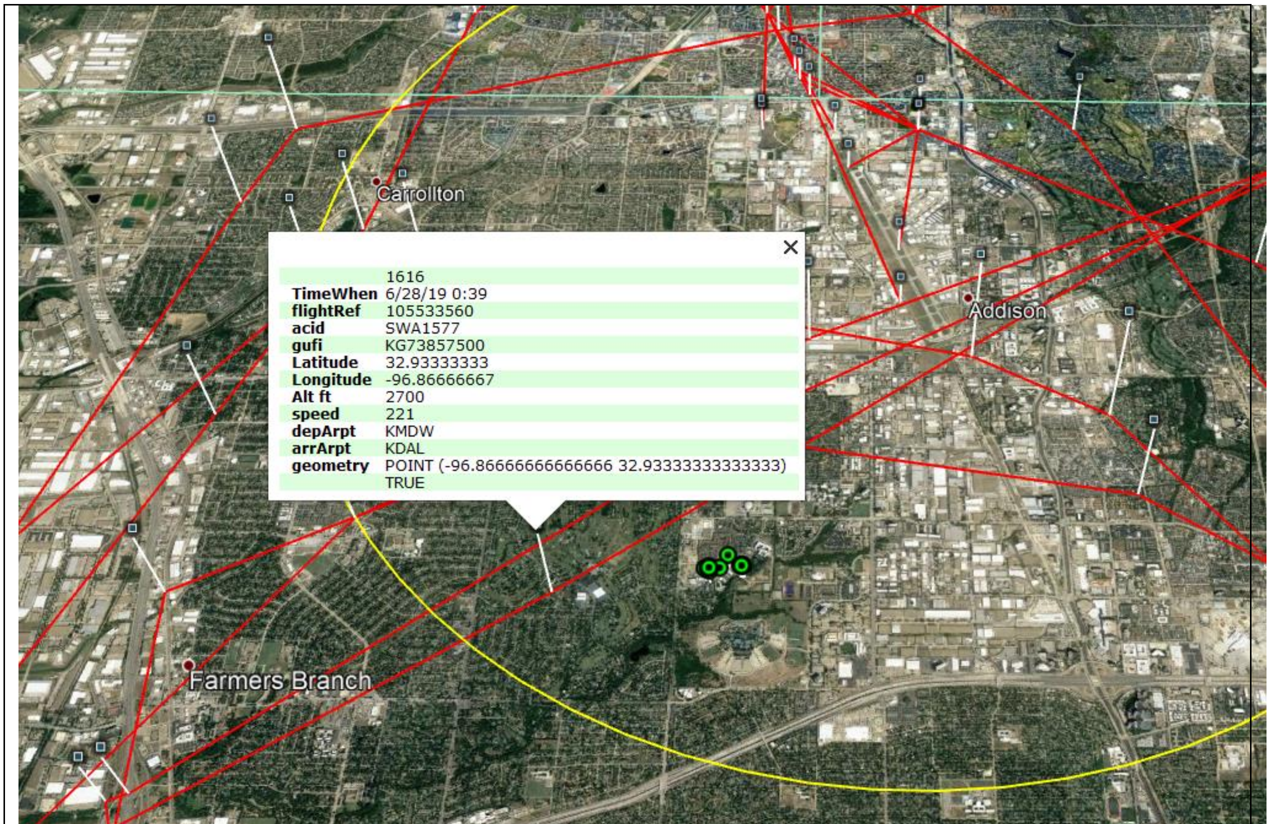


PRELIM INFO FROM FAA OPS: DALLAS, TX/UAS INCIDENT/1729C/DALLAS FORT WORTH TRACON ADVISED EUROCOPTER EC135, OBSERVED A SILVER/ORANGE QUADCOPTER UAS FROM THE 6 O'CLOCK POSITION WHILE HEADING EASTBOUND AT 1,200 FEET 4 N DALLAS EXECUTIVE ARPT. NO EVASIVE ACTION TAKEN. DALLAS FORT WORTH DPS

UAS MOR Alert for D10
Number: D10-M-2019/05/25-0002
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: May 25, 2019 - 2229Z
A/C: (EC135)

Summary: EC135 RPTD UAS AT 1200' MSL 4 MILES NORTH OF RBD AIRPORT. RBD ATCT NOTIFIED. SILVER/ORANGE QUADCOPTER. NO EVASIVE ACTION OR INJURIES RPTD. LAW INFORCEMENT CONTACT: DFW DPS.

Figure 114. Sample UAS sighting report telemetry and accompanying sighting report (correlated). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. In this near-perfect correlation, the reported position of both the aircraft and UAS were close in proximity and time. In this case, the UAS was detected at a maximum altitude of 66m (216 ft).

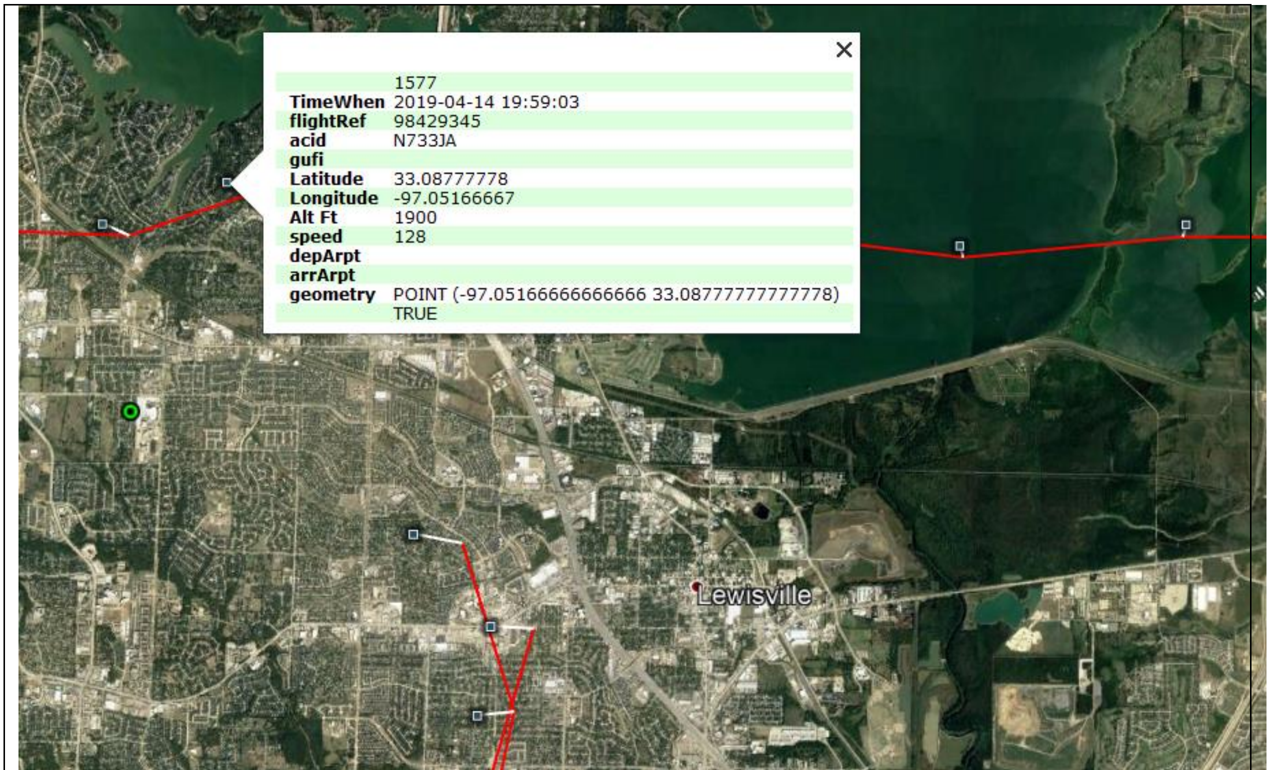


PRELIM INFO FROM FAA OPS: DALLAS, TX/UAS INCIDENT/1946C/C-ROC ADVISED BOEING B737 REPORTED A DARK, QUAD COPTER UAS, OPERATING AT 2,500 FEET 3 W ADDISON AIRPORT. NO EVASIVE ACTION TAKEN. LAW ENFORCEMENT NOTIFICATION NOT REPORTED.

UAS MOR Alert for D10
Number: D10-M-2019/06/27-0009
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: Jun 28, 2019 - 0046Z
A/C: BOEING B737

Summary: BOEING B737 WAS BEING VECTORED FOR A VISUAL APPROACH TO DAL. APPROXIMATELY 3 MILES WEST OF ADS AIRPORT, THEY REPORTED SEEING A DRONE APPROXIMATELY 500 FEET BELOW THEM, DARK IN COLOR. ADS TOWER NOTIFIED DUE TO CLOSE PROXIMITY TO THEIR AIRPORT. NO OTHER SIGHTINGS WERE MADE

Figure 115. Sample UAS sighting report telemetry and accompanying sighting report (correlated). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. This is another example of an accurate correlation between UAS telemetry, aircraft traffic, and sighting report data. In this example, the UAS was detected at a maximum altitude of 42m (137 ft AGL).



PRELIM INFO FROM FAA OPS: DALLAS, TX/UAS INCIDENT/1503C/C-ROC ADVISED CESSNA C172, REPORTED PASSING 2 UAS, 1 BLUE AND 1 SILVER COLORED, AT 1,800 FEET WHILE HEADING EASTBOUND BOUND DESCENDING INTO DALLAS AIR PARK AIRPORT, DALLAS, TX (F69). NO EVASIVE ACTION TAKEN. CLOSEST PROXIMITY WAS 300 FEET. DFW AIRPORT DPS NOTIFIED.

UAS MOR Alert for ADS
Number: ADS-M-2019/04/14-0001
Type: Hazardous and/or Unauthorized UAS Activity
Date/Time: Apr 14, 2019 - 2003Z
A/C: (C172)

Summary: C172 REPORTED PASSING 2 UAS AIRCRAFT (1 BLUE & 1 SILVER). C172 WAS AT 1,800 FEET HEADING EASTBOUND AND DESCENDING FOR DALLAS AIRPORT (F69). NO EVASIVE ACTION WAS TAKIN BY THE PILOT.

Figure 116. Sample UAS sighting report telemetry and accompanying sighting report (correlated). Aircraft telemetry displayed in red; and UAS telemetry displayed in green. This is another example of an accurate correlation between UAS telemetry, aircraft traffic, and sighting report data. In this example, the UAS was detected at a maximum altitude of 22m (72 ft AGL).

8.4.3 Discussion & Conclusions

Sighting report correlation was challenged by the fact the research team did not possess identifying information for the reporting aircraft. Reasonable efforts were made to search for supporting or amplifying information, such as searching for aircraft type from an aircraft registration number passing reasonably close to UAS activity at the time of a sighting event. This effort ensured that correlated events met all factual criteria that were able to be validated with the data set.

The research team observed that Iin many cases, pilot estimations of distance and altitude to UAS were much closer than the data indicated. This phenomenon seems to support previous UAS visibility study research by Loffi, Wallace, Jacob, and Dunlap (2016) that indicated relatively poor accuracy with regard to pilot estimations of distance to converging UAS.

For sightings data that was able to be correlated to telemetry, most incidents do not generally present indications of serious aviation hazards. Most sightings were for UAS operating at low altitude below 400 feet AGL. The researchers assert that Tthe vast majority of these correlated sightings represent merely aircraft observations of non-hazardous UAS activity. Further analysis sighting data and accompanying telemetry could be performed to assess UAS compliance with local LAANC grid limitations.

While the research team was unable to validate all reported UAS sightings, the established methodology shows promise as means of leveraging empirical data to analyze UAS sighting reports. For future analysis, the research team recommends the use of aircraft traffic data with higher temporal and spatial resolution, such as ADS-B.

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Appendix A1: Use Case Definitions from A18

Use Case Definitions

Where possible, these general uses are broken down further into more specific sub-categories of their respective general uses. This allows for collection of a greater amount of information. The definition of each general use and their respective sub-categories is considered as follows:

Aerial Data Collection: Use cases that are either described simply as "Aerial Data Collection" (or having a very similar description) or can most accurately be described as a use involving the collection of data by means of sensors or cameras on-board of the sUAS. Separate from the definitions of "Aerial Surveying / Mapping," "Agriculture," "Inspection," and "Research," the description given of the use case is not necessarily specific as to what data are collected, and for which purposes the data are used.

> **Aerial Data Collection – Construction/Mining:** A use case that was approved by the FAA in a 333 exemption request for the collection of non-specified data from construction and/or mining-related sites.
>
> **Aerial Data Collection – Environmental:** A use case that was approved by the FAA in a 333 exemption request for the collection of data from the environment for non-specified reasons.
>
> **Aerial Data Collection – General:** A use case that was approved by the FAA in a 333 exemption request for the collection of non-specified data from non-specified areas, or is simply listed as "Aerial Data Collection," "Aerial Acquisitions," etc.
>
> **Aerial Data Collection – Insurance:** A use case that was approved by the FAA in a 333 exemption request for the collection of non-specified data for insurance purposes that does not indicate that it is being used for inspection.

Aerial Photography/Videography: Use cases that are either described simply as "Aerial Photography/Videography" (or having a very similar description) or can most accurately be described as a use involving the collection of pictures and videos for no other obvious or implied reason than to have the pictures or videos collected in the applications listed below.

> **Aerial Photography/Videography – Closed-set filming:** A use case that was approved by the FAA in the 333 exemption request set for the collection of aerial images and videos collected for films, web videos, music videos, etc., from a closed-set.
>
> **Aerial Photography/Videography – Construction:** A use case that was approved by the FAA in the 333 exemption request set for collection of aerial images and videos of construction sites, where the use case does not indicate that data are collected for analysis, surveying, mapping, inspection, research, or surveillance.
>
> **Aerial Photography/Videography – General:** A use case that was approved by the FAA in the 333 exemption request set for collection of aerial videos and images when the use case cleared is simply listed as "Aerial Photography/Videography," "Aerial Photography," "Aerial Videography," etc.
>
> **Aerial Photography/Videography – News-Gathering:** A use case that was approved by the FAA in the 333 exemption request set for the collection of aerial images and videos to be used in the news-reporting media, whether it be newspaper, magazine, web content, mobile news, etc.
>
> **Aerial Photography/Videography – Outdoor Activities:** A use case that was approved by the FAA in the 333 exemption request set for collection of aerial images and videos that show uses in outdoor activities such as golf, hiking, climbing, rafting, team sports, etc.

Aerial Photography/Videography – Real Estate: A use case that was approved by the FAA in the 333 exemption request set for the collection of aerial images and videos that show structures and properties for the promotion and sale of real estate.

Aerial Photography/Videography – Wedding: A use case that was approved by the FAA in the 333 exemption request set and is listed as "Wedding Photography," or describes collection of aerial images and videos from weddings.

Aerial Surveying/Mapping: Use cases that are either described simply as "Aerial Surveying/Mapping" (or having a very similar description) or can most accurately be described as a mapping or surveying operation for various purposes.

Aerial Surveying/Mapping – Agriculture/Mining: A use case that was approved by the FAA in the 333 exemption request set for collection of aerial surveying and mapping data for agricultural and/or mining purposes that does not fit the description or specificity of the general, or precision agricultural use case parameters.

Aerial Surveying/Mapping – Construction: A use case that was approved by the FAA in the 333 exemption request set for collection of aerial surveying and mapping data of construction sites or structures.

Aerial Surveying/Mapping – Engineering: A use case that was approved by the FAA in the 333 exemption request set for collection of aerial surveying and mapping data of generally listed sites for engineering purposes.

Aerial Surveying/Mapping – General: A use case that was approved by the FAA in the 333 exemption request set for collection of general aerial surveying and mapping data, or when the use case is simply listed as "Aerial Surveying and Mapping," "Aerial Surveying," "Aerial Mapping," etc.

Agriculture: Use cases that are either described simply as "Agriculture" (or having a very similar description) or can most accurately be described as an application involving the collection of data for agricultural purposes.

Agriculture – Crop Monitoring: A use case that is listed as "Crop monitoring," or was approved by the FAA in the 333 exemption request set to fly over crop fields, collecting data regarding various measures of crop status.

Agriculture – General: A use case that is listed simply as "Agriculture," or was approved by the FAA in the 333 exemption request set for sub-types of agricultural data collection that does not meet the definition of "Agriculture – Crop Monitoring" or of "Agriculture – Precision Agriculture."

Agriculture – Precision Agriculture: A use case that is listed as "Precision Agriculture," or was approved by the FAA in the 333 exemption request set to scout agricultural regions for the use of precision agriculture, or describes uses that fall under the definition of precision agriculture. These include soil data collection, aerial imaging using various sensors, GPS-guidance of agricultural technologies, etc.

Emergency Services: Use cases that are either described simply as "Emergency Services" (or having a very similar description), or that can be described as aiding police officers, firefighters, medical services, etc., or for investigation of areas that are too dangerous to put a human being in for investigative purposes.

Emergency Services – Crisis Response: A use case that is listed as "Crisis Response" or was approved by the FAA in the 333 exemption request set for aiding law enforcement with various tasks, are able to relay messages in a crisis scenario, in considering emergency preparedness, etc.

Emergency Services – General: A use case that is listed as "Emergency Services" or with similar wording, is described with ambiguous-enough wording that it is not clear whether the use was for either crisis response or the investigation of hazardous regions specifically, or describes the use of sUAS for a form of emergency services covered by neither the definitions of crisis response nor investigation of hazardous regions.

Emergency Services – Investigate Hazardous Regions: A use case that is listed as "Investigation of Hazardous Regions" or was approved by the FAA in the 333 exemption request set to investigate an area that is too dangerous for a human to investigate directly. These include regions that are on fire, involve radiation, where footing is weak, etc.

Flight Training/Education: Use cases that are either described simply as "Flight Training," "Education" (or having a very similar description), or involve training employees, students, or other users in the operation of sUAS technology and/or procedures. Use cases involved in educating individuals regarding sUAS principles, or in demonstrating concepts in mathematics and sciences that can demonstrated with sUAS technologies.

Flight Training/Education – Education: A use case that is listed as "Education," or describes the teaching of mathematical, science, etc., concepts through the use of sUAS technology.

Flight Training/Education – General: A use case that is described with ambiguous enough wording that it is not clear whether it is for either flight training or education specifically.

Flight Training/Education – sUAS Training: A use case that is listed as "Training," or describes the training of users in operating sUAS.

Inspection: Use cases that are either described simply as "Inspection" (or having a very similar description), or that involve the inspection of different kinds of structures or areas for safety, upkeep, maintenance, etc.

Inspection – Communications Structures: A use case that involves inspection of communication structures including, but not limited to, cell towers, satellite dishes, etc.

Inspection – Construction: A use case that involves inspection of construction sites and structures under construction using sUAS.

Inspection – General: A use case that includes multiple sub-types of inspection through use of sUAS or is simply listed as "Inspection."

Inspection – Insurance: A use case that includes inspection for insurance purposes through the use of sUAS.

Inspection – Oil/Pipeline: A use case that involves inspection for the oil industry, including drilling structures and oil transportation pipelines through the use of sUAS.

Inspection – Power plants: A use case that includes inspection of power plant structures (such as power lines), resources, and operations through the use of sUAS.

Inspection – Real Estate: A use case that includes inspection of real estate structures and properties (including roofs) through the use of sUAS.

Inspection – Structure: A use case that includes inspection of structures, including non-real-estate-buildings (for architectural and integrity inspections) and infrastructure including roads, bridges, etc., through the use of sUAS.

Inspection – Wind power: A use case that specifically includes inspection of wind power turbines through the use of sUAS.

Marketing: Use cases that are either described simply as "Marketing" (or having a very similar description) or involve capture of aerial images and videos for the express purpose of using them for marketing of a business, product, or service.

Marketing – Aerial Images: A use case that specifically involves marketing through use of aerial image/video captured using sUAS.

Marketing – General: A use case that is listed simply as "Marketing" or describes sUAS applications other than aerial image/video capture for marketing purposes (such as demonstrations).

Multiple Applications: Use cases that are either described simply as "Multiple Applications" (or having a very similar description) or have been cleared for more than one general use case.

Research: Use cases that are either described simply as "Research" (or having a very similar description) or involve imaging and data collection distinctly for scientific research purposes.

Research – Academics: A use case for academic research. Examples include archaeological, ecological, architectural, and engineering data collection for academic research.

Research – Development: A use case that involves research for development of sUAS technology, or for the development of sUAS use protocol.

Research – General: A use case that involves sUAS usage in general research or is listed simply as "Research."

Research – Market: A use case that involves sUAS usage in Market research.

Research – Operations: A use case that involves research of operational applications of a drone. Examples include the study of flight techniques for different applications, such as search/rescue, emergency services, agricultural scouting, etc.

Research – Product Testing: A use case that involves testing of sUAS platforms and components.

Research – Transportation: A use case that involves inspection of traffic patterns using sUAS.

Search/Rescue: Use cases that are either described simply as "Search/Rescue," or involve use of sUAS to aid in various search and rescue operations.

Surveillance, Monitoring, etc.: Use cases that are either described simply as "Surveillance" or "Monitoring," or having a description that can be categorized in a similar fashion.

Monitoring – Environmental: Use cases that involve wildlife and environmental monitoring over different timeframes.

Monitoring – General: Use cases that are either simply described as "Monitoring," or something similar.

Monitoring – Legal: Use cases that include applications for legal purposes, including gathering of evidence.

Monitoring – Safety: Use cases that include applications for safety purposes.

Monitoring – Security: Use cases that include applications for security purposes.

From the data collected, Aerial Photography/Videography had the most use cases by 333-exemption holders, with 13,262 granted between September 2014 and 29 June 2016. The other most common general use cases included Inspection (7596), Aerial Surveying/Mapping (4116), Flight Training/Education (2399), and Search/Rescue (1917).