# Final Report
# ASSURE A28: Disaster Preparedness and Response Using UAS
# Volume 1: Research Results

June 1, 2022

v 1.0

## NOTICE

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# TECHNICAL REPORT DOCUMENTATION PAGE

**1. Report No.**
A28 -

**2. Government Accession No.**

**3. Recipient's Catalog No.**

**4. Title and Subtitle**
Final Report
ASSURE A28: Disaster Preparedness and Response using UAS

**5. Report Date**
September 26 2022

**6. Performing Organization Code**


**7. Author(s)**
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**8. Performing Organization Report No.**


**9. Performing Organization Name and Address**
University of Alabama in Huntsville
University of Alaska Fairbanks
Mississippi State University
New Mexico State University
North Carolina State University
Oregon State University
University of Vermont


**10. Work Unit No.**

**11. Contract or Grant No.**
A11L.UAS.68: Disaster Preparedness and Response

**12. Sponsoring Agency Name and Address**
Federal Aviation Administration

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**13. Type of Report and Period Covered**
Final Report (March 2020-June 2022)

**14. Sponsoring Agency Code**
5401

**15. Supplementary Notes**
Conducted in cooperation with the U.S. Department of Transportation, Federal Aviation Administration, ASSURE UAS Center of Excellence.


**16. Abstract**
The Alliance for System Safety of UAS through Research Excellence (ASSURE) team was tasked by the Federal Aviation Administration (FAA) with research related the safe integration of Uncrewed Aircraft Systems (UAS) into the disaster preparedness and response areas. This research will look at how UAS can aid in disaster preparedness and response to different natural and human-made disasters. It will focus on procedures to coordinate with the Department of Interior (DOI), the Department of Homeland Security (DHS) including the Federal Emergency Management Agency (FEMA) and other federal, local and state governments to ensure proper coordination during those emergencies.


**17. Key Words**

**18. Distribution Statement**
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

**19. Security Classification (of this report)**
Unclassified

**20. Security Classification (of this page)**
Unclassified

129

**22. Price**

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

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| | |
|---|---|
| AFV | Autonomous Flying Vehicle |
| AGL | Above Ground Level |
| AI | Artificial Intelligence |
| AOB | Air Operations Branch |
| AOBD | Air Operations Branch Director |
| ASSURE | Alliance for System Safety of UAS through Research Excellence |
| ATC | Air Traffic Control |
| BVLOS | Beyond Visual Line of Sight |
| CAP | Civil Air Patrol |
| COA | Certificate of Waiver or Authorization |
| CONOPS | Concept of Operations |
| DHS | Department of Homeland Security |
| DOI | Department of Interior |
| DSRS | Disaster Support Reservation System |
| EMA | Emergency Management Agency |
| FAA | Federal Aviation Administration |
| FEMA | Federal Emergency Management Agency |
| GCS | Ground Control Station |
| ICS | Incident Command System |
| IoT | Internet of Things |
| LAANC | Low Altitude Authorization and Notification Capability |
| LiDAR | Light Detection and Ranging |
| MBSE | Model-based Systems Engineering |
| MEMA | Mississippi Emergency Management Agency |
| MSU | Mississippi State University |
| NAS | National Airspace System |
| NCSU | North Carolina State University |
| NIMS | National Incident Management System |
| NMSU | New Mexico State University |

| | |
|---|---|
| NOAA | National Oceanic & Atmospheric Administration |
| NOTAM | Notices to Airmen |
| NTXPSURT | North Texas Public Safety Unmanned Response Team |
| ORA | Operational Risk Analysis |
| OrSU | Oregon State University |
| PI | Principal Investigator |
| PII | Personally Identifiable Information |
| PoC | Point of Contact |
| RPIC | Remote Pilot in Command |
| SAR | Search and Rescue |
| SfM | Structure from Motion |
| SGI | Special Government Interest |
| SOP | Standard Operating Procedure(s) |
| SOSC | System Operations Support Center |
| sUAS | Small UAS |
| SysML | Systems Modeling Language |
| TFR | Temporary Flight Restriction |
| UAF | University of Alaska-Fairbanks |
| UAH | The University of Alabama in Huntsville |
| UAS | Uncrewed Aircraft Systems |
| UTM | UAS Traffic Management |
| UVM | University of Vermont |
| VLOS | Visual Line of Sight |

# 1 EXECUTIVE SUMMARY

The research conducted under this project has focused on examining how UAS have been and are currently being used in emergency response scenarios. The team completed a deep dive review examined historical data on 38 disasters including floods, fires, weather events, earthquakes, and tsunamis to discern the nature of the incident, who were the responding agencies, what processes and procedures were used, what kinds of aircraft and associated equipment were involved, and what kinds of data resulted from the use of UAS

The research team conducted an extensive survey over several months targeting emergency responders to discern what their experience using UAS in emergency situations had been and what lessons might be learned from their experience. The survey responses provided insight into the current and previous relationships and communications among various agencies engaged in disaster response. The survey also provides current information on the kinds of equipment currently in use by first responders, how that equipment is being used, what responders' key concerns are, what training they feel they need, and other insights to aid FAA understanding of the current state of UAS usage in emergency response situations.

The research team completed an operational risk analysis looking at specific UAS use cases to understand the challenges, risks and mitigation measures associated with each. Researchers also examined the technological underpinnings that affect and enable the use of UAS in emergency response environments. The study includes a discussion of key challenges associated with these technologies.

This information will be useful in guiding researchers and the FAA in the development of drills, exercises, and workshops in the follow-on phase of research. Follow-on events in the next phase are focused on developing better integration of UAS assets and relationships between agencies at the local, state, federal, and tribal levels. The goal is to develop more efficient and effective communications and interactions among and between the members of the emergency response teams during the practical exercises that follow in Phase II of this research.

# 2 INTRODUCTION/PURPOSE OF RESEARCH

The Federal Aviation Administration (FAA) tasked The Alliance for System Safety of UAS through Research Excellence (ASSURE) team to conduct research that will provide insight into the safe integration of Uncrewed Aircraft Systems (UAS) into the disaster preparation and response activities. This research looks at how UAS could aid in disaster preparedness and response to different natural and human-made disasters. It focuses on coordination between the Department of Interior (DOI), the Department of Homeland Security (DHS) including the Federal Emergency Management Agency (FEMA), and other federal, local, and state governments to ensure safe and efficient integration of UAS during emergencies. The research developed the requirements, technical standards, policies, procedures, guidelines, and regulations needed to enable emergency response operations for UAS. Effective and efficient use of UAS in a disaster are the two primary goals of this project. The results are intended to offer an effective tool to assist first responders in saving lives and accelerate personnel and infrastructure recovery.

This research is divided into Phase I and Phase II, each with clear research questions and objectives. Successful completion of this Phase I of research sheds important insights into interactions between human factors, technology, and procedures, and will further improve regulatory processes and practices that govern UAS integration into the National Airspace System (NAS). This research will enhance UAS use in disaster response by making UAS use more effective and more efficient. Developed streamlined processes will drive UAS use in an organized manner.

The University of Alabama – Huntsville (UAH) directed the overall project, ensuring coordination of the participating universities, each with their assigned subtasks. The participating universities, along with UAH include:

- University of Alaska-Fairbanks (UAF),
- New Mexico State University (NMSU),
- University of Vermont (UVM) – Subcontractor to UAH,
- Oregon State University (OrSU),
- Mississippi State University (MSU), and
- North Carolina State University (NCSU).

The participating universities have completed extensive research and operational conduct across natural and human-made disasters using UAS.

# 3 BACKGROUND OF RESEARCH

As evidenced by the variety of use cases uncovered in the literature review, the emergency response community has been energetic and creative in making use of UAS in real disaster scenarios. They have been more open to adopting and adapting drone technology to the challenges of the disaster response environment – urgent needs, complex organizational relationships, lines of authority, difficult or non-existent lines of communication, adverse and extreme weather considerations, and regulatory issues. The FAA recognized the need for dedicated research into this unique community of users for the emerging technology represented by UAS.

# 4 RESEARCH APPROACH

The research conducted under this project has focused on examining how UAS have been and are currently being used in emergency response scenarios. The team examined historical data on specific disasters to discern the nature of the incident, who were the responding agencies, what processes and procedures were used, what kinds of aircraft and associated equipment were involved, and what kinds of data resulted from the use of UAS. Several paths were followed in pursuing this knowledge:

- An extensive survey was conducted over several months targeting emergency responders to discern what their experience using UAS in emergency situations had been and what lessons might be learned from their experience. Regional symposia and professional conferences were used to focus on a restricted target audience.
- An evaluation of well-documented disaster response situations was conducted using a commercial Model-based Systems Engineering toolset to develop entity relationship diagrams. These studies provide insight into the current and previous relationships and communications among various agencies engaged in disaster response. The hope is that in Phase II of this effort, these entity relationship diagrams will enable the team to develop more efficient and effective communications and interactions among and between the members of the emergency response teams.
- The team completed a “deep dive” literature study examining 38 historical disasters including floods, fires, weather events, earthquakes, and tsunamis. The results of this research are included in the Appendix entitled “Historical Disaster Characterization Report.”
- A series of Concepts of Operations (CONOPS) have been developed as possible candidates to be used in Phase II of this research program as practical exercises, workshops, table-top exercises, or other learning events. During these events, formal processes and procedures will be developed for each CONOP.
- The team conducted research examining the technological underpinnings that affect and enable the use of UAS in emergency response environments. The team provides an overview of some commonly used advanced technologies in emergency management/disaster response situations and discusses a number of challenges associated with some of these technologies.
- Analysis was completed looking at specific UAS use cases and usage challenges. Each of the use cases identified was analyzed in depth to determine the aspects of the use case that exposed it to risk.
- The team produced an operational risk analysis focusing on the kinds of missions, equipment, and conditions associated with disaster response.

# 5 RESEARCH RESULTS

## 5.1 Survey

The online survey was developed in Qualtrics through an iterative process with input from an expert advisory committee. It targeted both users and non-users of UAS across six professional sectors. The survey consisted of 43 total questions and 2 primary branches. Respondents were directed to the appropriate branch based on their response to the question, “Does your organization have a UAS program?” in the Introduction question block. The “yes” branch has a maximum of

38 potential questions. The "no" branch has a maximum of 13 potential questions. The number of questions displayed to a respondent within each branch was determined by question responses and subsequent display logic.

Details of the survey, including the questions asked, branching logic, and detailed results are included in Appendix A.

### *5.1.1 Participants*

There were 85 respondents. The largest percentage came from the federal government (23.5%) followed by the private sector (21.2%, local agency (14.1%), academic institution (14.15), state agency (12.9%), and non-profit (9.4%). 38 states were represented in the survey from every FEMA region.

### *5.1.2 UAS Program*

15 respondents reported not having a UAS program. 2 were unsure, the remaining all came from organizations that had a UAS program. Most reported that their UAS program consisted of certified operators, UAS data managers/analysts, that they owned UAS platforms and sensors, and that they has UAS-specific policies and procedures. A clear majority of respondents had fully operational UAS programs, with far fewer in the implementing, planning, or discussion phases.

### *5.1.3 Disaster Response*

Most of the respondents indicated that they employ UAS for disaster response. Approximately half said the same about occupied aircraft. The use of satellite imagery was less common, with only a third of respondents reporting using it. The use of occupied aircraft for disaster response was largely split with respondents reporting that their organization never uses occupied aircraft for disaster response to those who use it multiple times per year. 26 respondents indicated that they participate in multi-agency exercises that involve airspace coordination at least once per year. A slightly lower amount (18) indicated that they never do. Fewer than 10 reported that they engage in such exercises once per year. Those who participated in such exercises tended to be from western states, where such exercises in support of wildfire response are common. Most reported employing UAS technology for disaster response at least once in the past 5 years. When asked about the use of various remote sensing acquisition platforms (UAS, occupied aircraft, satellites) the vast majority said that the use of UAS would either considerably increase or somewhat increase. On average, respondents said their use of occupied aircraft would most likely stay about the same and that the use of satellite imagery would increase.

### *5.1.4 Coordination & Planning*

Organizational coordination during a disaster was most common among federal, state, and local agencies. It was far less common among the non-profit, academic, and private sector groups. Most reported incorporating UAS into their emergency response plans to some extent, with nearly half stating they had very detailed procedures in place. 68% indicated they have an individual dedicated to coordinating the airspace during a disaster. The majority indicated that they would find it valuable to participate in future disaster response exercises. That being said, most also reported that funding to participate in such an event was a challenge either some or most of the time.

### *5.1.5 Regulations & Safety*

Over half indicated that they operate UAS under Part 107, with 28% under a Part 91Certificate of Authorization (COA). The remainder indicated they function under an FAA test site or special waiver. Respondents were generally optimistic about Remote ID with over 70% stating that they thought Remote ID either would or might improve their ability to operate UAS in a disaster more safely. Over 70% reported having a moderate to a strong understanding of UAS regulations. 14% indicated that operator fatigue impacted flight operations at some point in time. Respondents were varied in where they reported staying up to date on UAS regulations. The FAA website topped the list with professional organizations, FAA emails, people within their organization, and conferences also ranked highly.

#### *5.1.6 Barriers*

Funding topped the list of the internal barriers to implementing UAS technology during a disaster. This was followed by buy-in from the leadership, training, staffing, and data standards. Most stated their organization saw the value of UAS technology. When it came to external barriers the restrictions on purchasing UAS technology based on country of origin and federal regulations were the most cited. Less cited external barriers included state/local regulations, and risk. Airspace coordination and data sharing were most often ranked as moderate barriers. For training, most indicated the UAS data processing and analytics would improve their operational capacity. Flight operations and pilot proficiency were ranked below other training such as specialized mission profiles and advanced sensor technology. For improving cross-organizational trust during a disaster the top-ranked certifications were in flight operations, pilot proficiency, and mission profiles.

#### *5.1.7 Privacy, Data Sharing, and New Technology*

When asked what portions of UAS data were considered to be sensitive, faces and license plates were ranked highest. Respondents largely indicated that they have decent communication, data storage, data dissemination, flight locking, and analytical capabilities. Most were either somewhat or very comfortable incorporating AI into UAS operations. None reported being not at all comfortable.

### 5.2 Disaster Research – Case Studies – Historical Disaster Characterization

The research team conducted an intense literature survey focusing on a set of known disasters in which UAS played some role. These included the following:

- Tornadoes
    - Amherst County Tornado-VA, 2018
    - Tescot Tornado–KS,2018
    - Lee County Tornado –AL, 2019
- Volcano
    - Kīlauea Volcano Eruption–HI, 2018
- Subsidence
    - Pasco County Sinkhole Collapse–FL, 2017
- Technological
    - Northfield Amtrak Train Derailment –VT, 2015
    - Refugio Oil Spill –CA, 2015
    - DuPont Amtrak Train Derailment –WA, 2017
    - Permian Basin Methane Leaks–TX & NM, 2018
    - Lincoln County Helicopter Crash –NV, 2020
    - Nashville Bombing –TN, 2020

- Hurricane, Derecho, Microburst
  - Addison County Microburst –VT, 2017
  - Hurricane Irma –FL, 2017
  - Hurricane Harvey –TX& LA, 2017
  - Hurricane Florence–NC, 2018
  - August Derecho–IA, 2020
  - Hurricane Delta –LA& MS, 2020
  - Hurricane Ida –LA, 2021
- Pandemic
  - COVID-19 Pandemic Prescription Delivery Service –FL, 2020
  - COVID-19 Social Distancing Monitoring-VT, 2020
- Landslide, Avalanche
  - Avalanche Control Monitoring–WA, 2006-2007
  - SR 530 Mudslide-WA, 2014
  - West Salt Creek Landslide–Collbran, CO, 2014
  - Transportation Corridor Landslide Assessments-AK, 2016
  - Grand County Avalanche–CO, 2020
- Seismic
  - Earthquake-Puerto Rico, 2020
- Wildland Fires
  - Parker 2 Wildfire –CA, 2017
  - Santa Rosa Wildfires –CA, 2017
  - Weaver Dunes Fire –MN, 2017
  - Maroon Wildfire –AZ, 2019
  - Taylor Creek and Klondike Wildfires –OR, 2018
  - Wildfires in Oregon –OR, 2020
- Flood
  - Blanco River Flood–TX, 2015
  - Johnson County Floods –TX, 2015
  - Little Androscoggin River Flood –ME, 2015
- Industrial-Urban Fires
  - Crotona Park North Fire –NY, 2017
  - Oil Well Fire –CO, 2020

A summary description of the Case Studies follows. A more complete presentation of each case study is found in Appendix B.

### *5.2.1 Wind & Storm – Hurricanes*

#### 5.2.1.1 2017 Hurricane Harvey, LA-TX

*UAS Applications Identified in Response:*

UAS enabled faster, safer Search and Rescue (SAR) and provided mapping and imagery data used for damage, flood, and infrastructure assessments.

*Key Lessons Learned:*

This UAS response marked the largest known organized response of UAS by public officials for a federally declared disaster in the U.S. The response involved many collaborating organizations and operators piloting a variety of UAS systems. Multirotor UAS were used more before the hurricane, during the event, and in the response phase, while fixed-wings were used most in the disaster recovery phase. Challenges included crowded airspace and a lack of strict airspace regulation from the FAA. Pre-existing relationships between local actors and UAS response organizations greatly benefitted the response.

#### 5.2.1.2 2017 Hurricane Irma, FL

*UAS Applications Identified in Response:*

UAS were deployed for SAR operations and enhanced situational awareness for responders. UAS also collected mapping data and imagery for infrastructure damage assessments.

*Key Lessons Learned:*

UAS involvement in SAR and situational awareness enhanced the efficiency of SAR operations. The UAS data from damage assessments was highly detailed. This response demonstrated effective coordination between many organizations to collect, process, analyze, and share UAS data. Challenges included loss of cellular networks following the hurricane, which complicated communication and data sharing.

#### 5.2.1.3 2018 Hurricane Florence, NC

*UAS Applications Identified in Response:*

Pre-storm flights were used to collect baseline data for post-storm comparisons. UAS imagery and video were collected in the wake of the hurricane and used to assess traffic conditions, road closures, and flood extent. UAS data were also used to authenticate reports of hazards and informed resource allocation.

*Key Lessons Learned:*

UAS operations were managed by a single organization, overseeing successful deployment of 15 UAS teams. This response was planned over a week before Hurricane Florence hit. One team operated Beyond Visual Line of Sight (BVLOS) under a COA. There was regular daily communication between UAS teams and managing group about Temporary Flight Restrictions (TFRs) and daily tasks. All UAS operations were coordinated with the FAA and other major federal/state agencies involved to prevent interference with occupied aviation.

#### 5.2.1.4 2020 Hurricane Delta, LA

*UAS Applications Identified in Response:*

UAS collected post-storm imagery of flooded regions along the Mississippi River.

*Key Lessons Learned:*

The use of UAS in this response enabled cost-efficient, rapid data sharing that in turn, informed decision making and improved forecasting accuracy.

#### 5.2.1.5 2021 Hurricane Ida, LA

*UAS Applications Identified in Response:*

UAS provided cellular data coverage following the storm, aided in SAR operations, conducted damage and insurance assessments, collected imagery of damage, and supported first responders and law enforcement.

*Key Lessons Learned:*

UAS were successfully used to provide cellular data in areas where cell signal was lost due to damage. Having cellular coverage enabled other emergency response operations (UAS and non-UAS) and increased communication and accessibility to local communities.

### *5.2.2 Wind & Storm – Tornadoes*

#### 5.2.2.1 2018 Amherst, VA

*UAS Applications Identified in Response:*

UAS imagery and video informed damage assessments, documented recovery efforts, and provided situational awareness to emergency responders.

*Key Lessons Learned:*

UAS data informed and documented disaster response and recovery efforts. UAS operations were led by a high school technology club and their advisor. They worked with emergency management service and local Sheriff's offices throughout the response. This response demonstrated that even a small and localized UAS operation can be effective in the wake of a disaster.

#### 5.2.2.2 2018 Tescot, TX

*UAS Applications Identified in Response:*

UAS conducted damage assessments and site investigations following the incident.

*Key Lessons Learned:*

UAS, flown in Visual Line of Sight (VLOS), were able to collect data in remote/inaccessible locations and were a cost-effective option.

#### 5.2.2.3 2019 Lee County, AL

*UAS Applications Identified in Response:*

UAS provided support during SAR operations and helped increase situational awareness.

*Key Lessons Learned:*

The UAS response was cost-effective and more efficient than dispatching occupied aircraft. When combined with infrared sensors, UAS also provided increased search capabilities for SAR teams. Regular, daily communication occurred between UAS operators and local officials.

#### 5.2.2.4 2021 Tornadoes, KY

*UAS Applications Identified in Response:*

UAS imagery, video, and mapping products were used to document and communicate the extent of damage following the storm.

*Key Lessons Learned:*

The rapid speed at which UAS data was shared benefitted emergency response and public awareness. UAS imagery and video coverage utilized by news outlets provided a broader perspective of storm damage and more accurately communicated the urgency and scale of the catastrophe.

### *5.2.3 Wind & Storm – Wind*

#### 5.2.3.1 2017 Microburst, VT

*UAS Applications Identified in Response:*

UAS provided up-to-date mapping products and imagery of property damage following the microburst.

*Key Lessons Learned:*

UAS data informed damage assessments and was made publicly available and accessible. The UAS data provided much more up-to-date imagery than satellite imagery could provide.

#### 5.2.3.2 2020 Derecho, IA

*UAS Applications Identified in Response:*

UAS were used to increase efficiency of post-storm damage assessments, especially in otherwise inaccessible locations.

*Key Lessons Learned:*

Due to the increased accessibility and aerial perspective they provided, UAS made damage assessments more efficient than traditional ground-based methods.

### *5.2.4 Wind & Storm – Flood*

#### 5.2.4.1 2015 Blanco River, TX

*UAS Applications Identified in Response:*

UAS were utilized for SAR operations and collected imagery used for mapping and damage assessment. These data helped to identify priority areas requiring response and to inform future disaster preparedness planning.

*Key Lessons Learned:*

Challenges included delayed flying due to crowded airspace, delayed receipt of an emergency COA, and issues with power outages and cellular connectivity. UAS operators communicated with Air Traffic Control (ATC) to request and adjust an emergency COA because requesting a COA through the FAA was too slow. Later in the response, the FAA established a TFR covering 13 miles along the Blanco River, in which, BVLOS UAS operations were permitted. Both multirotor and fixed-wing UAS of varying sizes were used in the response and provided different functions.

#### 5.2.4.2 2015 Johnson County, TX

*UAS Applications Identified in Response:*

UAS assisted in SAR operations by helping emergency responders to rapidly locate stranded people and delivering floatation devices.

*Key Lessons Learned:*

UAS were helpful in rapid SAR operations, especially when major flood conditions made areas completely inaccessible. UAS can be extremely helpful due to their versatility beyond providing live video streams, including the ability to transport floatation devices to stranded people.

#### 5.2.4.3 2015 Little Androscoggin River, ME

*UAS Applications Identified in Response:*

UAS were used to transport a floatation device to someone stranded in a river and live video was used to survey downstream river conditions to plan rescue efforts.

*Key Lessons Learned:*

The key components of this case were quick deployment of UAS, the ability of UAS to carry flotation devices, and live video feed capabilities to inform rescue efforts. UAS also provided useful documentation of the rescue.

### *5.2.5 Geohazards - Volcano*

#### 5.2.5.1 2018 Volcanic Eruption, Kilauea, HI

*UAS Applications Identified in Response:*

UAS provided real-time monitoring data for scientists and emergency managers. UAS also provided situational awareness and supported emergency response efforts like hazard tracking, evacuation, and SAR. Visible and thermal imagery, video, and gas emissions measurements were collected with UAS.

*Key Lessons Learned:*

This case marked the first known use of UAS for volcanic eruption disaster response in the U.S. The operations demonstrated successful coordination and collaboration from many local, state, and federal organizations. UAS response time, data collection, and processing abilities were quick and low cost. Waivers were obtained to operate at night and above 400ft Above Ground Level (AGL).

### *5.2.6 Geohazards – Seismic*

#### 5.2.6.1 2020 Earthquake, Puerto Rico

*UAS Applications Identified in Response:*

UAS imagery and video informed response efforts and resource allocation. The data were used to document damage, assess impacts on the community, and to identify locations for emergency infrastructure. UAS collected data at low altitudes when weather conditions prevented occupied aviation from flying.

*Key Lessons Learned:*

UAS were utilized for longer-term, post-disaster response and support, which occurred over the span of 3 months. More than 13,000 photos and videos were collected. Civil Air Patrol (CAP) assumed the role of managing coordination with other involved parties and occupied aviation. The ability to quickly process and share UAS data enabled rapid documentation.

### *5.2.7 Geohazards – Landslide*

#### 5.2.7.1 2013 SR530 Mudslide, WA

*UAS Applications Identified in Response:*

UAS were used to assess further landslide and flooding risk, collect hydrological and geological data, and provide access to inaccessible/dangerous areas. UAS real-time video and imagery informed flood mitigation and hazard risks.

*Key Lessons Learned:*

UAS allowed first responders to limit the need to direct access dangerous areas. Challenges included lack of launching/landing space for the UAS, coordination issues, potential interference with other aircraft, inability to get a COA for one UAS, and privacy concerns. Light Detection and Ranging (LiDAR) and thermal sensor payloads could improve data collection in future responses.

#### 5.2.7.2 2014 Landslide, West Salt Creek, CO

*UAS Applications Identified in Response:*

UAS data were used to map, model, and monitor the landslide. UAS informed decisions about which areas were safe for ground crew entry and their thermal capabilities were used for SAR and mapping.

*Key Lessons Learned:*

UAS increased emergency response efficiency and was cost-effective compared to other methods of surveying, performing SAR, and gathering data. UAS use increased first responders' safety and provided remote access to dangerous areas. UAS data products furthered scientific understanding of the landslide and informed future monitoring.

#### 5.2.7.3 2016 Landslide Assessment, AK

*UAS Applications Identified in Response:*

UAS data products were used to evaluate rock-slope stability and to monitor transportation risks near highly trafficked roads.

*Key Lessons Learned:*

UAS were able to capture more data compared to terrestrial LiDAR. In addition, the remote launch and land abilities of UAS made them a safer option than terrestrial LiDAR. UAS data products were deemed capable for use in landslide assessments.

### *5.2.8 Geohazards - Subsidence*

#### 5.2.8.1 2017 Sinkhole, FL

*UAS Applications Identified in Response:*

UAS data were used to monitor surface terrain changes and to inform stabilization/recovery efforts.

*Key Lessons Learned:*

UAS were able to rapidly deploy and gather accurate data to increase response efficiency. UAS data were easy to integrate with other data sources and facilitated analysis of the causes behind the sinkhole.

### *5.2.9 Geohazards – Avalanche*

#### 5.2.9.1 2007 Avalanche Monitoring, WA

*UAS Applications Identified in Response:*

UAS were used for avalanche control and monitoring and traffic monitoring in areas with higher avalanche risk.

*Key Lessons Learned:*

UAS captured useful aerial imagery for traffic monitoring. UAS technology had potential to constructively supplement Washington State Department of Transportation's existing avalanche control practices. Additional research is needed for effective application of UAS for avalanche monitoring and control.

##### 5.2.9.2 2020 Avalanche SAR, CO

*UAS Applications Identified in Response:*

UAS were used in conjunction with ground search crews for a SAR mission in response to an avalanche. The search was conducted after sunset.

*Key Lessons Learned:*

UAS increased situational awareness and provided a useful aerial perspective for responders on the ground.

#### *5.2.10 Technological – Pandemic*

##### 5.2.10.1 2020 COVID-19 Social Distance Monitoring, VT

*UAS Applications Identified in Response:*

UAS collected video that was used for social distance monitoring to inform park management procedures.

Simple video products provided useful data that informed park management decisions in a COVID-safe way. The ability of Low Altitude Authorization and Notification Capability (LAANC) to provide real-time airspace authorizations was valuable for this response.

##### 5.2.10.2 2020 Medical Delivery UPS and CVS, FL

*UAS Applications Identified in Response:*

UAS delivered essential medications from a local pharmacy to a nearby retirement community in a COVID-safe and efficient way.

*Key Lessons Learned:*

This pilot effort demonstrated coordination, collaboration, and problem solving between multiple companies, like CVS, UPS, Matternet, and a retirement community to find a creative solution to a wide-reaching problem.

#### *5.2.11 Technological – Oil Spill*

##### 5.2.11.1 2015 Refugio Oil Spill, CA

*UAS Applications Identified in Response:*

UAS were utilized to map a beach and the ocean after an oil spill for damage assessment and response purposes.

*Key Lessons Learned:*

Collecting data with UAS provided insight to the involved agencies around what technology and practices can be improved moving forward. The response and National Oceanic & Atmospheric Administration's (NOAA) involvement resulting in increased interest in UAS technology and led to a workshop focused on UAS for oil spill responses. The UAS response demonstrated rapid response, planning, data collection, and processing. This response also demonstrated the need for further development of how the technology can be used for oil spill responses and generated interest and concepts for further oil spill response training.

### *5.2.12 Technological – Terrorism*

#### 5.2.12.1 2020 Nashville Bombing, TN

*UAS Applications Identified in Response:*

UAS captured images and video to document damage from the blast and impact on surrounding infrastructure. UAS data also served to communicate both the detailed and broader scale of the damage.

*Key Lessons Learned:*

UAS video and imagery were used by emergency response organizations and media to gain further insight into impacts from the disaster and to increase public understanding and scale of the event.

### *5.2.13 Technological – Vehicular*

#### 5.2.13.1 2015 Train Derailment, VT

*UAS Applications Identified in Response:*

UAS helped document the incident by collecting imagery and mapping the train derailment. UAS data and products were used to inform subsequent investigations into the event.

*Key Lessons Learned:*

UAS response, data collection, processing, and sharing were rapid and greatly enhanced recovery and future mitigation efforts.

#### 5.2.13.2 2017 Train Derailment, WA

*UAS Applications Identified in Response:*

UAS captured aerial photos and videos to document the incident. UAS data were used to map and reconstruct the crash scene.

*Key Lessons Learned:*

The crash scene recreation informed decision making and future mitigation efforts and showed effective integration of UAS data with other data. Challenges included disorganized and uncoordinated communication, which improved after the initial stages of the response.

### *5.2.14 Technological – Biohazard*

#### 5.2.14.1 2018 Methane Leaks, TX & NM

*UAS Applications Identified in Response:*

UAS used for pipeline inspections to detect methane leaks.

*Key Lessons Learned:*

BVLOS flight was permitted by the FAA, though BVLOS was not used. UAS were used in combination with artificial intelligence to conduct autonomous flight.

#### 5.2.14.2 2020 Lincoln County Helicopter Crash, NV

*UAS Applications Identified in Response:*

UAS helped authorities determine the extent of the crash and locate parts in the debris. UAS increased investigator's safety and increased efficiency in searching the difficult terrain.

*Key Lessons Learned:*

Two UAS were flown at the same time, but at slightly different altitudes to increase efficiency. Pre-planning was very important for coordination and to avoid collision and ensure consistent data. UAS data products, including 3D point clouds and high-resolution imagery, were used to inform the investigation following the crash.

### *5.2.15 Wildland Fires*

#### 5.2.15.1 2017 Santa Rosa Wildfires, CA

*UAS Applications Identified in Response:*

UAS imagery was collected for infrastructure and other damage assessments following the fire. Data products included 3D models and orthomosaics.

*Key Lessons Learned:*

UAS enabled faster and safer damage assessments by reducing the need for estimators to navigate debris, unstable structures, and other hazards. Challenges included highly trafficked airspace due to recreational UAS operating in restricted airspace, which limited emergency UAS operations. These incursions also prevented emergency responders from mitigating and managing the spread of fires. Following the response, the need to increase education for recreational UAS operators was identified.

#### 5.2.15.2 2017 Parker 2 Wildfire, CA

*UAS Applications Identified in Response:*

UAS were used for mapping fires within a 500-acre area. Data products were used to determine and analyze characteristics of the fire.

*Key Lessons Learned:*

UAS operated under a COA to conduct flights within the TFR. This marked the first time that a COA allowed for BVLOS operation, facilitating faster and more efficient data collection. A 3D infrared map was used to evaluate and quantify the amount of land burned from the fire. The use of UAS increased response efficiency and was far safer for emergency responders than traditional response tactics.

#### 5.2.15.3 2017 Weaver Dunes Fire, MN

*UAS Applications Identified in Response:*

UAS mapped a 320-hectare area prior to prescribed burning. UAS data were collected following the burns for change-detection analysis.

*Key Lessons Learned:*

UAS data was analyzed to determine characteristics of the fire and landscape. UAS was quick, cost efficient and provided high quality data compared to other imagery collection methods. Challenges included battery size and operating time limits of the UAS as well as image resolution and clarity issues, including inconsistent resolution and camera movement.

#### 5.2.15.4 2018 Taylor Creek & Klondike Wildfires, OR

*UAS Applications Identified in Response:*

UAS were used to remotely drop incendiary spheres to start fires. Thermal and true-color imagery were collected for monitoring purposes.

*Key Lessons Learned:*

UAS decreased risk by eliminating the need for someone to start the fires in-person. Thermal imaging operations took place at night. A major benefit of UAS is that they were able to fly where occupied aircraft could not. A federal employee served as the UAS Manager and managed communication between ground and air operations. This response showed how an operational system for UAS could be implemented between private operators and public incident commanders.

#### 5.2.15.5 2019 Maroon Wildfire, AZ

*UAS Applications Identified in Response:*

UAS monitored spot fires using thermal infrared imagery and video. UAS also conducted prescribed ignitions by dropping incendiary spheres.

*Key Lessons Learned:*

UAS reduced risk to ground crews and occupied aviation in an area with unpredictable hazards. UAS operators from the Bureau of Land Management led the successful UAS response. High amounts of communication were required to safely operate in a TFR.

#### 5.2.15.6 2020 Wildfires in Oregon

*UAS applications identified in response:*

Several agencies effectively utilized the UAS technology to support their response including mapping the burn area, monitoring the wildfires, assessing the damage, and evaluating long term effects such as impacts on wildlife and falling tree hazards.

*Key Lessons Learned:*

In response to these unprecedented wildfires, UAS technology was found to be effective in providing timely data and capturing improved imagery compared with crewed aircraft. Several challenges with current operational requirements were noted when operating UAS in emergency situations. First, it is difficult to maintain a fixed height of 400 ft or less in steep, narrow canyons with varying topography and substantial amounts of vegetation. Second, the absence of special disaster-related regulations or procedures led to delays or inability of field crews to perform work. Additionally, communication between crewed aircraft and UAS operators was challenging. Lastly, while substantial data were collected which were highly beneficial to the responding agencies, there were difficulties in management and sharing data due to the lack of standards and specific criteria, particularly associated with determining what data should be archived and what is disposable data to support the response.

### *5.2.16 Industrial-Urban Fires*

#### 5.2.16.1 2017 Crotona Park North Fire, NY

*UAS Applications Identified in Response:*

UAS streamed true color and thermal video to the incident commander.

*Key Lessons Learned:*

This event was the first time New York City Fire Department used a UAS. The success of the technology led to the New York City Fire Department furthering UAS operations.

#### 5.2.16.2 2020 Oil Well Fire, CO

*UAS Applications Identified in Response:*

UAS provided situational awareness during a fire at an oil facility.

*Key Lessons Learned:*

This was the first instance in which the fire department employed UAS. UAS helped to inform the decision as to when firefighters could approach the scene.

## *5.3* Model-based Systems Engineering (MBSE) Process Modeling and Diagramming

### *5.3.1 Introduction and Background*

In their roles within the FAA’s Center of Excellence for UAS Research, known as ASSURE, the institutions originally responsible for identifying entities involved in a disaster and their relationships were the University of Alabama—Huntsville (UAH), University of Vermont (UVM), North Carolina State University (NCSU), University of Alaska Fairbanks (UAF), Oregon State University (OrSU), and Mississippi State University (MSU). The A28 Disaster Preparedness and Response proposal had OrSU and MSU leading Task 2, which explored the current use of crewed aircraft for disaster response and the communication and coordination between federal, state, and local agencies during the disaster. Task 2 efforts began in the Fall of 2020 and focused on data collection and key interaction diagramming of working relationships between response agencies and the FAA. Following the project peer-review in November 2020, the lead university asked the MSU team to lead an effort that combined Task 2-2, defining the interface among the FAA, first responders, and agencies, and Task 5-3, developing an entity relationship diagram using the Commercial MBSE toolset. Together, MSU and UAH team members began working the combined tasks, with MSU leading/facilitating the effort and UAH providing the expertise on designing the populating of the MBSE toolset.

Section 5.3.2 details the approach to the entity relationship and diagramming project. Section 5.3.2.6 details the methodology used for the data analysis. Section 5.3.5 contains a summary of each disaster case study, with a reference to Appendix D where their respective diagrams and a summary on how the diagram should be read are located. Section 5.3.6 contains the analysis of the disaster case study diagrams. Section 5.3.8 contains the qualitative observations taken from the case studies and provides some general recommendations. Section 5.3.9 is the conclusion to the Diagramming Section of this report.

### *5.3.2 Entity Relationship and Diagramming Project Approach*

The project consisted of seven phases: 1) MBSE toolset utilization; 2) determination of diagramming; 3) determination of data collection methodology; 4) specific disaster data collection; 5) diagramming of specific disasters; 6) data analysis methodology; and 7) data analysis. As an iterative process, each phase laid the foundation and direction for the following project phase. The following paragraphs describe the project’s seven phases.

#### 5.3.2.1 MBSE Toolset Utilization

The team selected the NoMagic Cameo Enterprise Architecture© toolset to develop the MBSE diagramming. The goal was to best describe the coordination and communication among FAA, state, and local response agencies via entity relationship diagrams. Entity relationship diagrams are useful for visually understanding the role of different entities and their attributes and relationships during a disaster. However, entity relationship diagrams cannot display time-dependent interactions and the data flow occurring between the entities. The team explored the use of the MBSE system architecture modeling tool that conformed with the Object Management Group (OMG) Systems Modeling Language (SysML) version (v) 1.6 standard and supports dynamic system and mathematical (parametric) simulations. Expert reviews substantiated the Cameo Systems Modeler as a sound MBSE tool that supports most of the OMG SysML's syntax rules, semantic rules, basic requirements traceability, and intermediate dynamic and mathematical model simulations (MBSEworks,n.d.). In addition, the MBSE SysML could graphically represent text-based requirements and relate them to other model element requirements. The team explored ways to model for interactions between entities and associated data flow and identify time dependencies and efficiencies.

#### 5.3.2.2 Determination of Diagramming

After determining the utilization of the MBSE toolset, the team investigated which SysML diagram types would be most appropriate for capturing and describing the coordination and communication among FAA, state, and local response agencies during a disaster. Of the nine SysML diagram types, three types of diagrams were chosen to represent the relationship and interface levels between the disaster response entities: 1) Block Definition Diagram (BDD), 2) Use Case Diagram (UCD), and 3) Activity Diagram (AD). The following describes the three types of diagrams.

#### 5.3.2.3 Block Definition Diagram

A BDD is static in nature and shows system components, contents, relationships, conceptual entities, and logical abstractions. For the diagramming effort, block diagrams identified the relationship between organizations or responders involved with the disaster. An example of the disaster relationships between first responders, police, emergency medical services, and fire/rescue personnel, Incident Command System (ICS), and the Coast Guard is seen in

Figure 1.

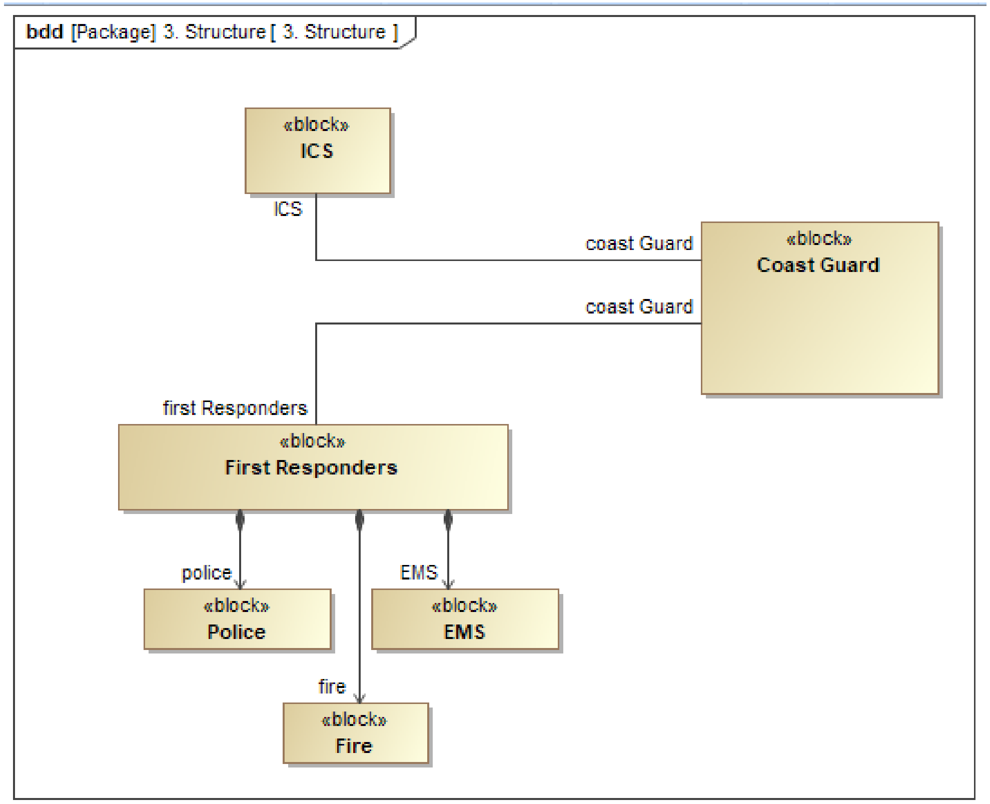


Figure 1. BDD for disaster response relationships.

### 5.3.2.4 Use Case Diagram

A UCD describes a system transaction, e.g., dataflow, with an external user. The external users are actors and can symbolize organizations, facilities, or people. UCD actors are represented by stick figures, and the system transactions are represented by ovals. For the diagramming effort, the goal was to represent dataflow topics and interface between organizations and responders during the disaster.

A use case example between the Coast Guard, first responders, and the ICS is seen in Figure 2. The topic of the dataflow interaction shown in Figure 2 is a mission request from first responders or the ICS, which is followed by the Coast Guard's internal process of assessing the mission, performing the mission and, after completing the mission, generating a mission summary. The mission summary is then provided to first responders and the ICS.

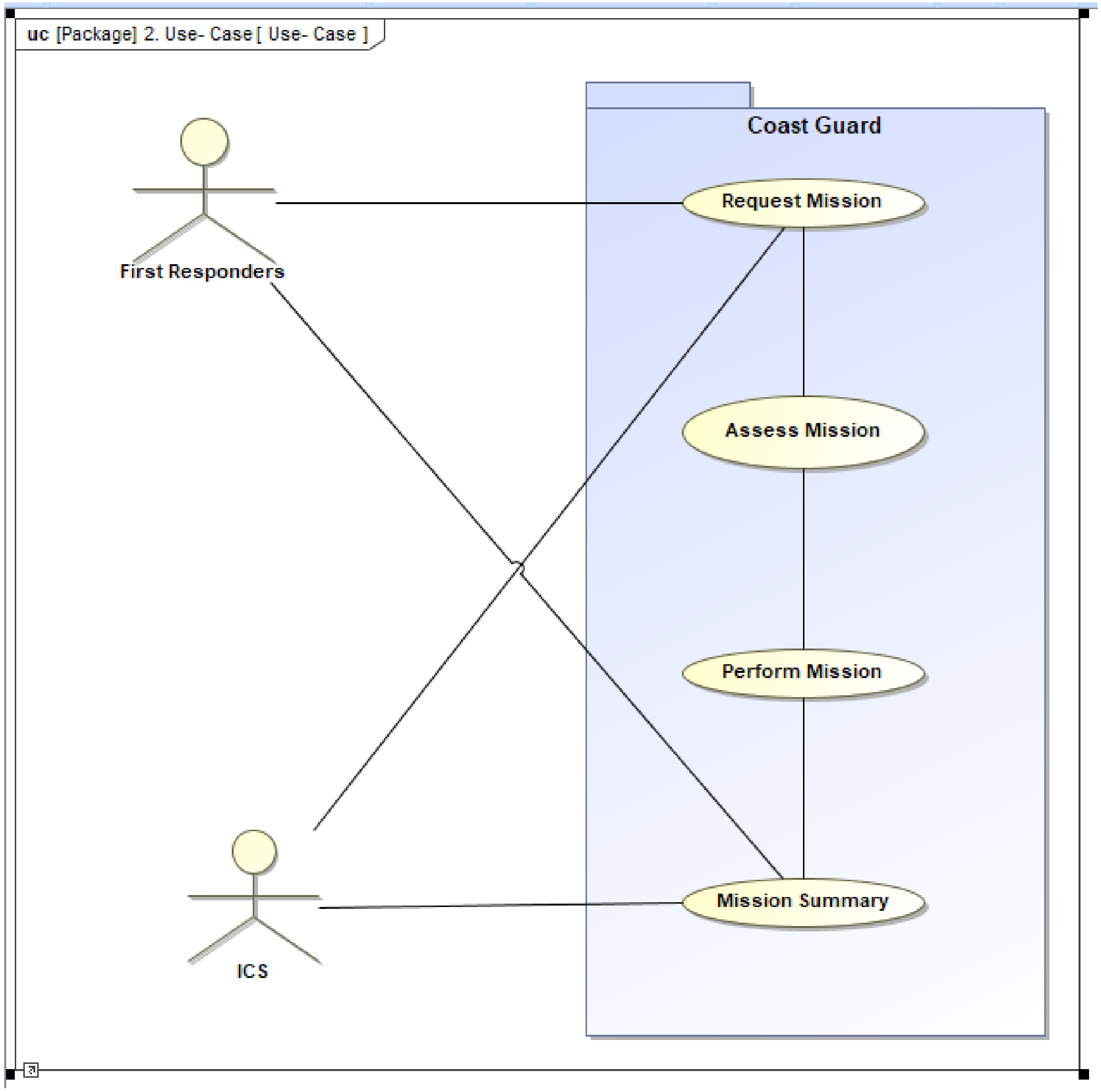


Figure 2. UCD for disaster response dataflow interface.

#### 5.3.2.5 Activity Diagram

The AD describes the dynamic behavior of the system and shows the flow of functional behaviors. The AD is a powerful tool for representing the sequence of actions and describes the behavior and dynamic element interactions. ADs can represent start to finish control flow with decision paths both sequential and concurrent. For the diagramming effort, ADs provide a detailed description of the disaster response from the perspective of the critical position (activity). Disaster specific ADs are often complicated and heavily reliant on the information available. Therefore, some disasters modeled in this report have multiple ADs but only contain the information provided and available during data collection.

An AD showing a disaster response critical interaction element is seen in Figure 3.

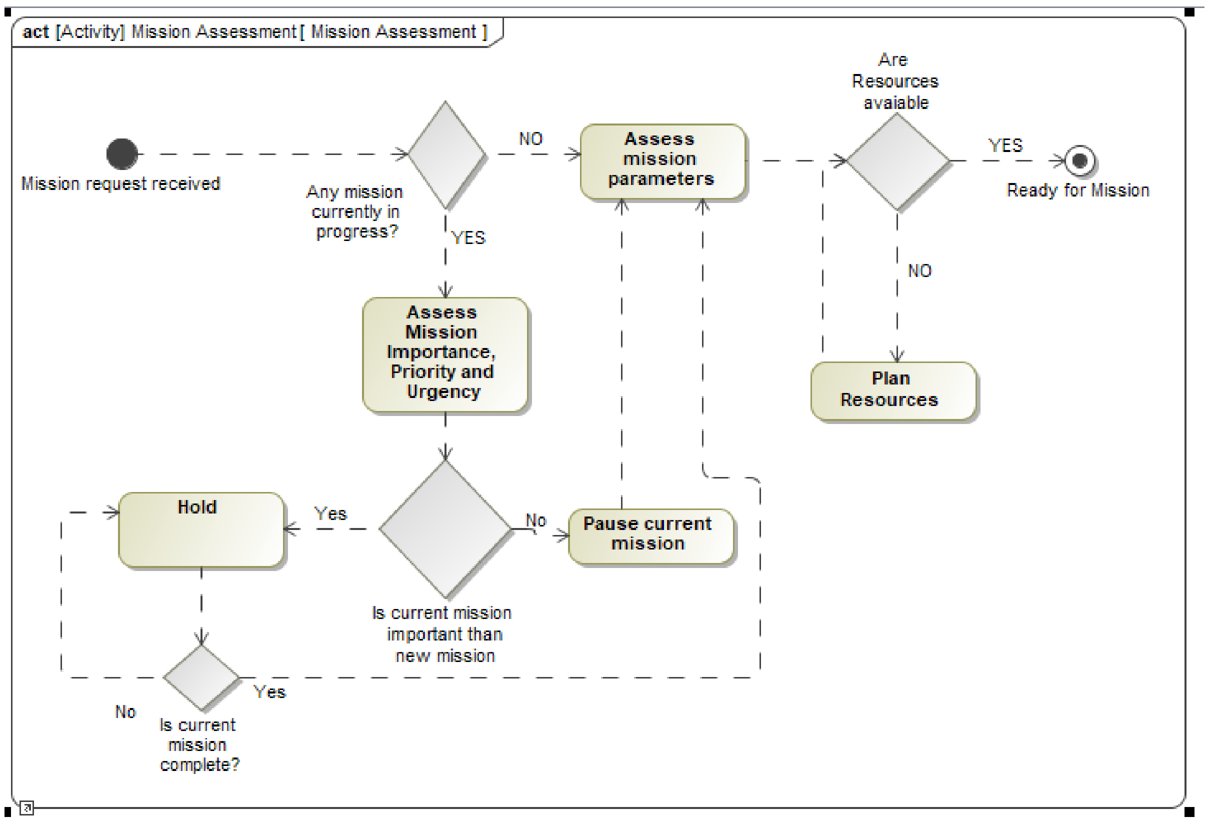


Figure 3. AD for disaster response mission assessment interaction.

ADs utilize specific notations representing the flow of functional behaviors as seen in Figure 4. An activity, represented by a rounded rectangle, represents a functional behavior, and a control flow represents the flow of functional behaviors. An object flow represents the data flow between an object and activity. Decision nodes, represented by a hollow diamond, indicate separate activities. Merge nodes, represented by a filled diamond, indicate merge activities. The starting node indicates where the reader should begin reading the diagram and is represented by a filled

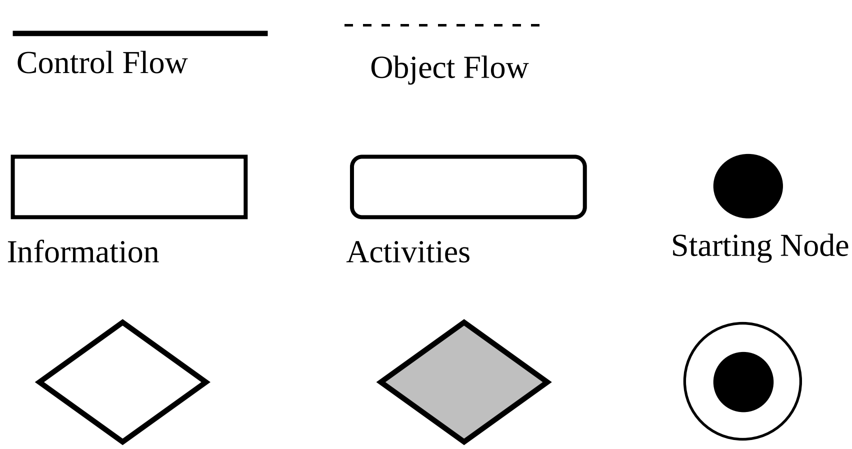


Figure 4. Activity Diagram notation.

circle. The end node indicates where the diagram ends and is represented by a circle with an inner filled circle (No Magic, Inc., 2021).

Once three types of diagrams were chosen to capture the relationship and interface levels between the disaster response entities, the team explored ways to improve the interpretation of diagramming. To better differentiate between each entity, a series of color codes were used. The FAA is represented in red, the local ATC is represented in orange, and any federal entity involved is colored gray. The agency targeted for data collection is colored cyan. State agencies who are not the targeted entity are colored green, and entities at the county or local level are colored magenta. Private entities are colored yellow. The entity color codes are listed in Figure 5 and shown in the three SysML diagrams in Figures 6, 7, and 8.

| Entity Color Codes | | |
|---|---|---|
| **Entity** | **Color** | **Hex Color Code** |
| FAA | Red | FF3333 |
| ATC | Orange | FF7C33 |
| Federal Entity | Grey | 808080 |
| Agency Consulted | Cyan | 00FFFF |
| Other State Agency | Green | 33FF00 |
| County/Local Level Entity | Magenta | FF33FF |
| Non-Profit/Private Entity | Yellow | FFFF00 |

Figure 5. Entity Color Codes Used

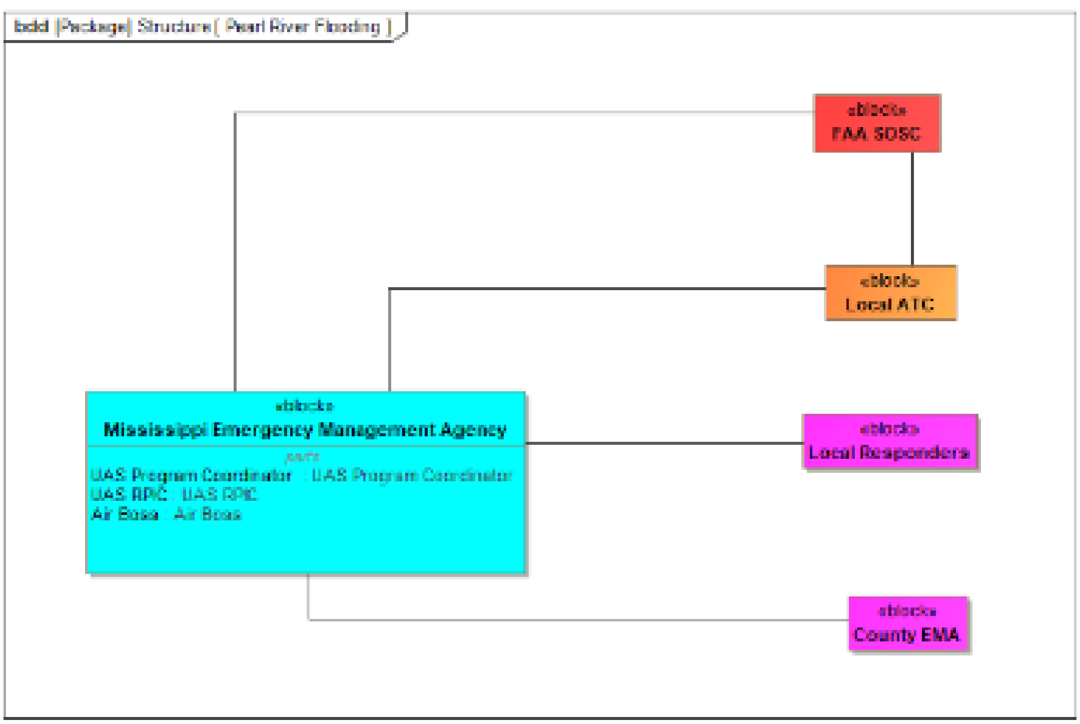


Figure 6. Entity Color Codes in BDD.

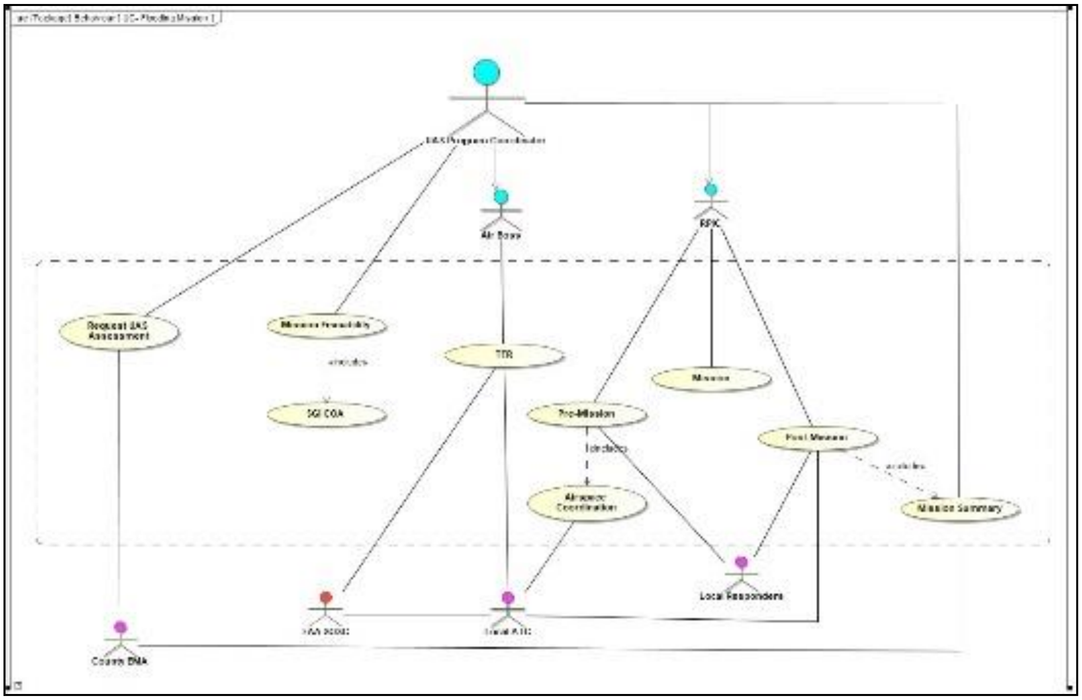


Figure 7. Entity Color Codes in UCD.

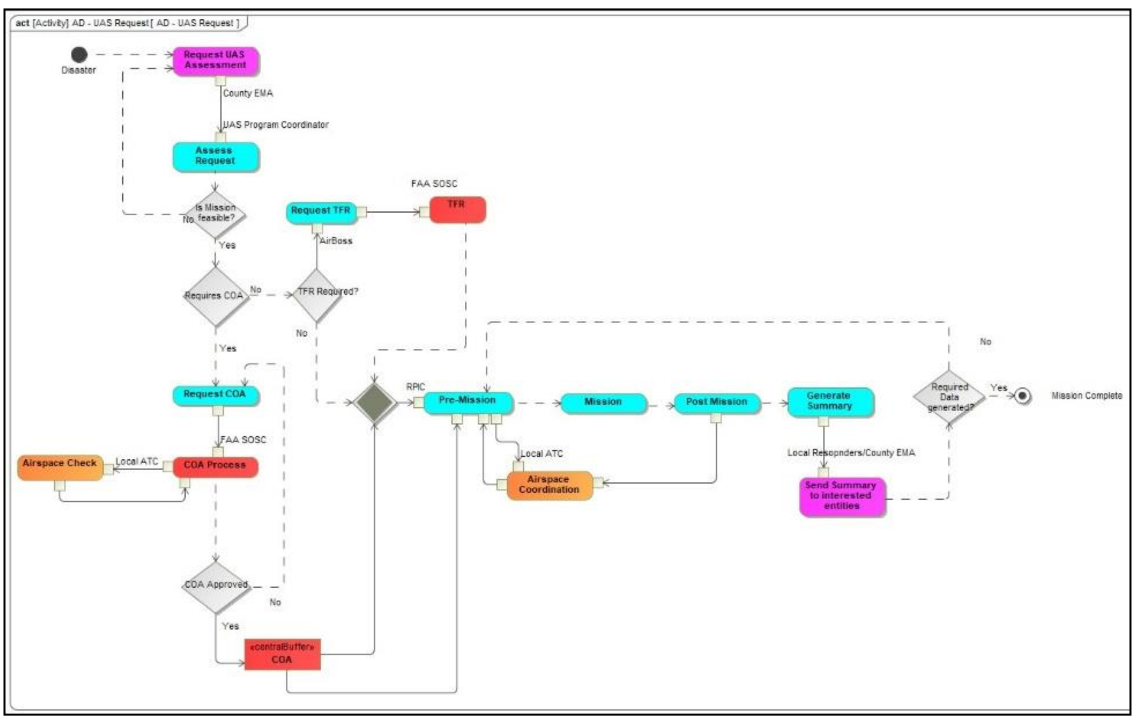


Figure 8. Entity Color Codes in AD.

### 5.3.2.6 Determination of Data Collection Methodology

To determine the role and use in disaster preparedness and response, the research team focused on specific disaster events occurring at the federal, state, and local level. The team's goal was to collect data from different types of disasters across the country to identify organizational relationships between disaster response entities and interfaces occurring during the disaster. The relationships identified during the disaster would be populated in the BDD. The interface between disaster entities would be modeled in the use case and ADs. Figure 9 shows how the data collection topics would populate the relationship and interface diagrams in the MBSE toolset. Data collection would seek interaction topics such as crew and aircraft staging, mission execution, including flight tasking, scheduled and on-call response, airspace coordination, and post flight responsibilities.

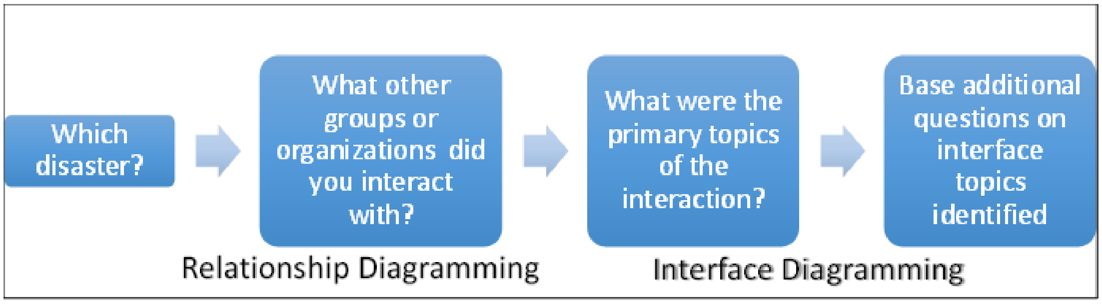


Figure 9. Relationship and Interface diagramming data collection methodology.

#### 5.3.2.7 Specific Disaster Data Collection

Project team members from the seven ASSURE universities involved in the project provided disaster response industry connections. Initial contact included 11 state and local entities and four federal disaster response entities. Of the 11 state and local entities contacted, data collection sessions occurred on nine specific disasters. Of the four federal agencies contacted, data collection occurred with all. Data was collected through a series of meetings with primary contacts representing critical response positions within their organizations. Disaster response entities were sought based on their role in disaster response. The Point of Contact (POC) with an entity was first identified and contacted to determine if they were willing to participate in the project and if the disaster involved relationships and interfaces with other response entities. The MSU Principal Investigator (PI) typically made initial contact with the disaster entity POC by email. Once the disaster entity POC expressed a willingness to participate, the project PI set up an initial meeting to discuss project details, and, specifically, the diagramming information of interest. The initial conversation was normally via telephone and included potential timeframes for data collection and answers to questions about the project. A follow-on data collection session was then scheduled to collect diagramming information. Care was taken to ensure each entity and disaster response was unique and covered a broad spectrum of UAS response activities. In each disaster data collection discussion, the POC described their functions and responsibilities during the disaster. The discussion was narrative in nature and loosely structured to allow the POC to steer the conversation to the most important relationships and interfaces. However, the way(s) in which the disaster was responded to and how the airspace coordination was handled during the event were always explored. All but one initial conversation led to a specific disaster data collection event.

Data collection sessions occurred for the following types of disasters and responses: 1) hurricane; 2) flooding; 3) tornado; 4) volcano; 5) train derailment; 6) construction crane collapse; 7) condominium collapse; 8) wildfire; and 9) missing person. The research data collection team was comprised primarily of the discussion leader and a note taker. Other members of the research team were present to ask questions and clarify statements made by the disaster entity POC. All discussions were done virtually and recorded for later referencing and diagramming. Permission to record was granted prior to the start of the discussion. Project team members from MSU managed the data collection events and collected and compiled the UAS response disaster information. A total of 13 project data collection sessions occurred from May through September, 2021. Nine of the entities provided information that was disaster specific and located within a specific state. Four federal agencies provided information for the project that was not disaster specific but general response information for all types of disasters.

*5.3.2.7.1 Diagramming of Specific Disasters*

Once the specific disaster discussion was complete, the information for each disaster was provided to the UAH project team for diagramming in the NoMagic Cameo Systems Modeler© toolset. In addition to the notes captured, the recorded disaster discussion was also made available to the UAH project team. After the UAH project team completed the initial diagrams for a specific disaster, MSU team members who participated in the data collection event reviewed the initial diagrams for accuracy. If necessary, disaster POCs were contacted for additional insight and clarification.

As seen in Table 1, not all disasters were diagrammed in the MBSE toolset. The Vermont train derailment lacked the multi-agency coordination and response sought for diagramming. It became apparent during the Oregon wildfire data collection that the information was focused on surveying, mapping, and postflight image processing occurring internally to the Department of Transportation (DOT) organization and did not fit the project goal of defining the interfaces among the FAA, first responders, and agencies during a specific disaster. Data were collected on the multi-month Hawaii volcano and Florida condominium collapse, but diagramming was not complete due to the unavailability of MBSE toolset personnel.

Table 1. MSU data collection events.

| Specific Disasters in MBSE Toolset | Disasters not in MBSE Toolset | Non-disaster Federal-level not in MBSE Toolset |
|---|---|---|
| **Mississippi Flooding** | Vermont Train Derailment | FAA System Operations Support Center (SOSC) |
| **Vermont Missing Person** | Hawaii Volcano | Federal Emergency Management Agency (FEMA) |
| **North Carolina Hurricane** | Oregon Wildfire | National Oceanic & Atmospheric Administration (NOAA) |
| **Texas Crane Collapse** | Florida Condominium Collapse | United States Forest Service (USFS) |
| **Texas Tornado** | | |

### *5.3.3 Data Analysis Methodology*

In addition to diagramming of specific disaster events occurring at the federal, state, and local level on the use of UAS in disaster preparedness and response, the project team also analyzed the information. The goal of the data collection analysis was to provide comprehensive and informative connections among disaster response agencies, summarize the results, and derive relevant managerial recommendations. The first step was studying disaster management connection information provided through specific disasters. The connection information was then converted into a matrix or graph for each disaster, and a new weighted graph was created by combining common agencies in all the disasters. The information from the weighted graph fed three types of analyses: 1) centrality analysis, 2) community detection analysis, and 3) connectivity analysis.

##### *5.3.3.1.1 Centrality Analysis*

The centrality analysis estimated and highlighted the importance of an agency in the disaster management network. The centrality analysis measured three areas: 1) degree centrality, which focused on estimating the importance of an agency for the disaster connectivity or the information flow of the agency network, 2) closeness centrality, which estimated how fast the information flowed through a given agency to other agencies, and 3) betweenness centrality, which identified the agencies that can control information flow and how frequently an agency was on the shortest paths between two agencies.

##### *5.3.3.1.2 Community Detection Analysis*

The community detection analysis was used to identify the interaction frequency of groups of agencies in the disaster management network.

##### *5.3.3.1.3 Connectivity Analysis*

The connectivity analysis determined how extensively connected two agencies were in the disaster management network.

Then three analyses were applied, and the results were recorded and fed an induced analysis that summarized and derived the managerial recommendations to the disaster response agencies.

Figure 10 shows the flow and connection of all analysis efforts.

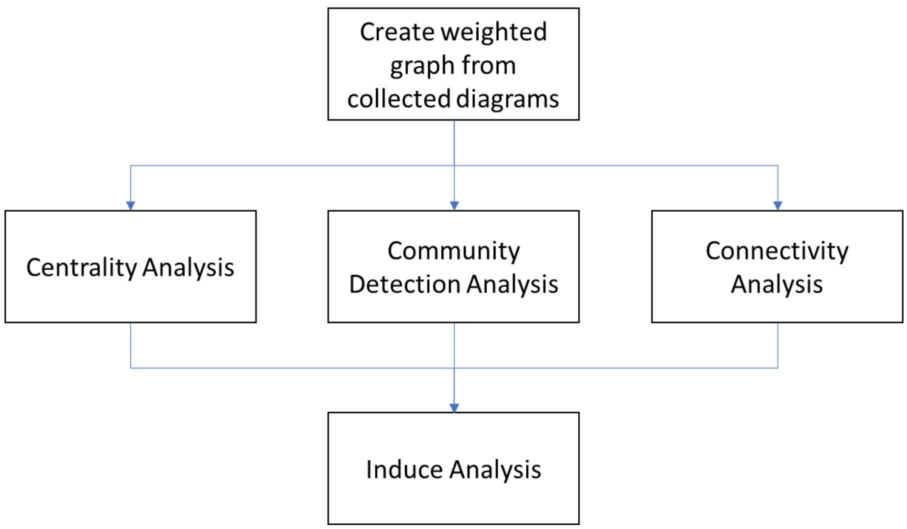


Figure 10. Analysis Flow and Connection.

### ***5.3.4 Data Analysis***

The data used for the analysis were the five specific disasters diagrammed in the NoMagic Cameo Enterprise Architecture© toolset. To properly reflect all necessary data and to increase the summary rigor of the comprehensive and informative connections among disaster response agencies, analysis could only begin after the completion of the tool set diagramming. Therefore, the analysis effort started at the beginning of December 2021 and was completed at the end of January 2022. The analysis process utilized multiple network science-based models and approaches. The concluding induced analysis was derived from the preceding summaries of the network science-based centrality analysis, community detection analysis, and connectivity analysis. The result of the analysis is found in Section 5.3.6 of this report.

### *5.3.5 Disaster Overviews*

#### 5.3.5.1 Mississippi Flooding—February 2019

On February 10, 2019, heavy rainfall and flooding overwhelmed the Ross Barnett Reservoir's capacity around the city of Jackson, Mississippi. Banks along the Pearl River rose, flooding homes and neighborhoods in Jackson, Rankin, Madison, and Hinds counties. On February 15, Governor Tate Reeves declared a state of emergency. Loss of life and damage to homes and property occurred during this disaster. The UAS Program Coordinator of the Mississippi Emergency Management Agency (MEMA) was interviewed for this disaster case. See Appendix C for the MBSE diagrams of this disaster response.

#### 5.3.5.2 Vermont Missing Persons—November 2020

A remote pilot from the Spatial Analysis Lab of the University of Vermont was interviewed about a missing persons case that occurred on November 10, 2020. The Spatial Analysis Lab is often contacted by local fire and police for its UAS capabilities. On November 10, 2020, a detective from the Burlington Police contacted the Spatial Analysis Lab for assistance with a missing persons search. The missing person's last known location was near Burlington Airport, in class D airspace. This required a Special Government Interest (SGI) waiver from the FAA Systems Operations Support Center (SOSC). See Appendix C for the MBSE diagrams of this disaster response.

#### 5.3.5.3 North Carolina Hurricane Florence—September 2018

Hurricane Florence made landfall on September 14, 2018 and spent the next two days producing record-breaking rainfall across eastern North Carolina. An estimated 74,563 structures were flooded, and 5,214 people were reportedly rescued from flooding. Nearly 140,000 North Carolinians registered for disaster assistance after the storm. South Carolina Emergency Management reported nine fatalities across the state; $607 million damage; 11,386 homes with moderate or major damage; 455,000 people evacuated, and 11 dams breached or failed. (Armstrong, 2018) The UAS Program Manager and the Airspace Coordinator from the North Carolina Department of Transportation were interviewed about their response to this disaster. See Appendix C for the MBSE diagrams of this disaster response.

#### 5.3.5.4 Texas Crane Collapse—June 2019

On June 9, 2019, a severe thunderstorm caused a crane to collapse onto the Elan City Lights Apartments. The collapse killed one woman, injured five others, and left 500 residents homeless. The president of the North Texas Public Safety Unmanned Response Team (PSURT) was interviewed about his team's response to this disaster. The interviewee also works for the Little Elm Fire Department. See Appendix C for the MBSE diagrams of this disaster response.

#### 5.3.5.5 Texas Tornado Response—October 2019

On October 20, 2019, 10 tornadoes tore through North Texas. The strongest tornado, a category EF-3, touched down near Interstate 35 and Walnut Hill Road. It traveled 15 miles, moving east through Preston Hollow before entering Richardson, Texas. The president of PSURT was interviewed about his team's response to this disaster. The interviewee also works for the Little Elm Fire Department. See Appendix C for the MBSE diagrams of this disaster response.

### *5.3.6 Analysis*

#### 5.3.6.1 Disaster Case Studies

#### 5.3.6.2 Weighted Graph Creation

##### *5.3.6.2.1 Individual Disaster Connection Matrix Creation*

A connection matrix was created for each disaster. For each disaster presented in Appendix C, the BDD was used to create a connection matrix. Tables 2, 3, 4, 5, and 6 show the connection matrix for each disaster:

Table 2. Mississippi Pearl River Flooding Disaster.

| | **Mississippi Emergency Management Agency (MEMA)** | **FAA** | **Local ATC** | **Local Responder** | **County EMA** |
|---|---|---|---|---|---|
| **Mississippi Emergency Management Agency (MEMA)** | X | 1 | 1 | 1 | 1 |
| **FAA** | 1 | X | 1 | 0 | 0 |
| **Local ATC** | 1 | 1 | X | 0 | 0 |
| **Local Responder** | 1 | 0 | 0 | X | 0 |
| **County EMA** | 1 | 0 | 0 | 0 | X |

Table 3. Vermont Missing Person Disaster.

| | **Spatial Analysis Lab** | **FAA** | **Local ATC** | **Local Police Dept.** |
|---|---|---|---|---|
| **Spatial Analysis Lab** | X | 1 | 1 | 1 |
| **FAA** | 1 | X | 1 | 0 |
| **Local ATC** | 1 | 1 | X | 0 |
| **Local Police Dept.** | 1 | 0 | 0 | X |

Table 4. North Carolina Hurricane Florence Disaster.

| | NC Dept. of Public Safety | NC Emergency Management | NC Dept. of Environmental Quality | NC Dept. of Transportation | UAS Program Manager | UAS Airspace Coordinator | FAA | Local ATC |
|---|---|---|---|---|---|---|---|---|
| **NC Dept. of Public Safety** | X | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **NC Emergency Management** | 1 | X | 0 | 0 | 1 | 0 | 0 | 0 |
| **NC Dept. of Environmental Quality** | 0 | 0 | X | 0 | 1 | 0 | 0 | 0 |
| **NC Dept. of Transportation** | 0 | 0 | 0 | X | 1 | 1 | 0 | 0 |
| **UAS Program Manager** | 0 | 1 | 1 | 1 | X | 1 | 0 | 0 |
| **UAS Airspace Coordinator** | 0 | 0 | 0 | 1 | 1 | X | 1 | 1 |
| **FAA** | 0 | 0 | 0 | 0 | 0 | 1 | X | 1 |
| **Local ATC** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | X |

Table 5. Texas Crane Collapse Disaster.

| | NCT Council of Govern. | Emergency Preparedness Coordinator | Dallas Urban Search and Rescue (USR) | NT Public Safety Unmanned Response Team (NTXPSURT) | ICS | Dallas Police Dept. | Dallas Fire Dept. | News Helicopters | UAV Pilot | OSHA | FAA | Local ATC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NCT Council of Govern.** | X | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Emergency Preparedness Coordinator** | 1 | X | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **USR** | 1 | 0 | X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **NTXPSURT** | 1 | 1 | 1 | X | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| **ICS** | 0 | 0 | 0 | 1 | X | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| **Dallas Police Dept.** | 0 | 0 | 0 | 0 | 1 | X | 0 | 1 | 0 | 0 | 0 | 0 |
| **Dallas Fire Dept.** | 0 | 0 | 0 | 0 | 1 | 0 | X | 0 | 0 | 0 | 0 | 0 |
| **News Helicopters** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | X | 0 | 0 | 0 | 0 |
| **UAV Pilot** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **OSHA** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 |
| **FAA** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | X | 1 |
| **Local ATC** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | X |

Table 6. Texas Tornado Disaster.

| | NTXPSURT | Secret Service | SS Coordinator | FAA | Local ATC | Medic | ICS | Fireman Division Chief | Fire Dept. | Dallas EOC emergency Operator | USR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **NTXPSURT** | X | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| **SS** | 1 | X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **SS Coordinator** | 1 | 1 | X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **FAA** | 1 | 0 | 0 | X | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Local ATC** | 0 | 0 | 0 | 1 | X | 0 | 0 | 0 | 0 | 0 | 0 |
| **Medic** | 0 | 0 | 0 | 0 | 0 | X | 0 | 1 | 0 | 0 | 0 |
| **ICS** | 1 | 0 | 0 | 0 | 0 | 0 | X | 1 | 0 | 0 | 0 |
| **Fireman Division Chief** | 1 | 0 | 0 | 0 | 0 | 1 | 1 | X | 1 | 0 | 1 |
| **Fire Dept.** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | X | 0 | 0 |
| **Dallas EOC Emergency Operator** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 |
| **USR** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | X |

#### 5.3.6.3 Weighted Matrix/Graph Creation

By combining several common agencies in these five disasters and removing redundant agencies, the project team recreated a weighted matrix/graph representing the connections among agencies for the five disasters. Table 7 shows the weight matrix/graph for the combined disasters.

Table 7. Weighted Connection Graph for Five Disasters.

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| State Emergency Management Agency | X | 1 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 0 |
| FAA | 1 | X | 5 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Local ATC | 1 | 5 | X | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Local Police Dept. | 0 | 0 | 0 | X | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| Local Fire Dept. | 0 | 0 | 0 | 0 | X | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| UAS Program | 2 | 5 | 4 | 1 | 2 | X | 1 | 1 | 0 | 2 | 0 | 1 |
| State Dept. of | 0 | 0 | 0 | 0 | 0 | 1 | X | 0 | 0 | 0 | 0 | 0 |

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Transportation** | | | | | | | | | | | | |
| **State Dept. of Environment Quality** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | X | 0 | 0 | 0 | 0 |
| **State Dept. of Public Safety** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |
| **Local Emergency Management Agency** | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | X | 0 | 0 |
| **Media** | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | X | 0 |
| **Local Council of Government** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | X |

### 5.3.6.4 Network Analysis

*5.3.6.4.1 Centrality Analysis*

In the centrality analysis, three types of analyses were performed: degree centrality, closeness centrality, and betweenness centrality. Tables 8, 9, and 10 show the analysis results.

Table 8. Degree Centrality Results.

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Degree | 6 | 11 | 10 | 2 | 3 | 19 | 1 | 1 | 1 | 3 | 2 | 1 |

Table 9. Closeness Centrality Analysis Result.

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Closeness Degree | 1.83 | 1 | 1.1 | 5.5 | 3.67 | 0.58 | 11 | 11 | 11 | 3.67 | 5.5 | 11 |

Table 10. Betweenness Centrality Analysis Results.

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Betweenness Degree** | 2 | 4 | 4 | 0 | 0 | 5 | 0 | 0 | 0 | 1 | 0 | 0 |

From degree centrality, the project team noted the UAS program was the most informative agency and had the largest number of connections in these five disasters; from closeness centrality, it is obvious that several state departments, i.e. state departments of transportation, environment quality, and public safety along with local councils of government, have the shortest information path to other agencies, which means these agencies can most efficiently obtain information from each other; from betweenness centrality, the UAS program can most frequently control information flow in the connections of agencies, followed by the FAA and the local ATC, respectively.

*5.3.6.4.2 Community Detection Analysis*

The community detection analysis aims to identify groups of agencies that are more connected within themselves than with the rest of other agency groups. By using the Markov Cluster Algorithm and the Newman-Girvan Fast Greedy Algorithm, the team clustered 12 agencies into four different groups: the FAA, local ATC, local emergency management agency and state emergency management agency are grouped; the local police department, local fire department, and UAS program are grouped; the state departments of transportation, environment quality, and public safety, along with local council of government, are grouped; and media have their own group. Based upon their functions and impacts on the disaster management, the team titled each group as follows: approval and coordination group (FAA, local ATC, local emergency management agency and state emergency management agency), disaster response group (local police and fire departments and the UAS program), support group (state departments of transportation, environment quality, and public safety, along with local council of government), and social media group (media). Figure 11 presents these clusters.

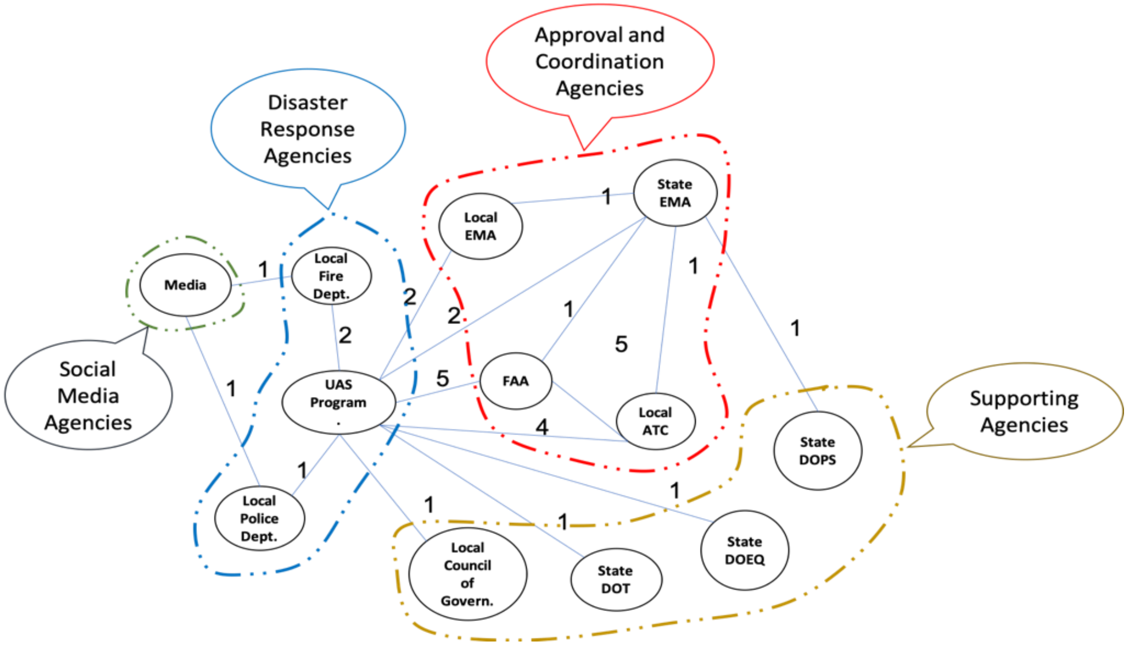


Figure 11. Agency Clusters.

### *5.3.6.4.3 Connectivity Analysis*

The connectivity analysis results show how extensively two agencies are connected. Table 11 shows the relationships. The FAA and local ATC have the strongest connection followed by the FAA and UAS program, the local ATC and UAS program, and the state EMA and UAS program, respectively. Other strong connections include the state EMA/FAA, the state EMA/local ATC, and the state EMA/local EMA. The connections within the same cluster/group will be stronger.

Table 11. Connectivity Analysis Results.

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **State Emergency Management Agency** | X | 1.28 | 1.15 | 0 | 0 | 2.16 | 0 | 0 | 0.23 | 1.09 | 0 | 0 |
| **FAA** | 1.28 | X | 3.26 | 0 | 0 | 2.72 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Local ATC** | 1.15 | 3.26 | X | 0 | 0 | 2.06 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Local Police Dept.** | 0 | 0 | 0 | X | 0 | 0.28 | 0 | 0 | 0 | 0 | 0.16 | 0 |
| **Local Fire Dept.** | 0 | 0 | 0 | 0 | X | 0.87 | 0 | 0 | 0 | 0 | 0.13 | 0 |
| **UAS Program** | 2.16 | 2.72 | 2.06 | 0.28 | 0.87 | X | 0.34 | 0.38 | 0 | 0.82 | 0 | 0.21 |
| **State Dept. of Transportation** | 0 | 0 | 0 | 0 | 0 | 0.34 | X | 0 | 0 | 0 | 0 | 0 |
| **State Dept. of** | 0 | 0 | 0 | 0 | 0 | 0.38 | 0 | X | 0 | 0 | 0 | 0 |

| | State Emergency Management Agency | FAA | Local ATC | Local Police Dept. | Local Fire Dept. | UAS Program | State Dept. of Transportation | State Dept. of Environment Quality | State Dept. of Public Safety | Local Emergency Management Agency | Media | Local Council of Government |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Environment Quality** | | | | | | | | | | | | |
| **State Dept. of Public Safety** | 0.23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | X | 0 | 0 | 0 |
| **Local Emergency Management Agency** | 1.09 | 0 | 0 | 0 | 0 | 0.82 | 0 | 0 | 0 | X | 0 | 0 |
| **Media** | 0 | 0 | 0 | 0.16 | 0.13 | 0 | 0 | 0 | 0 | 0 | X | 0 |
| **Local Council of Government** | 0 | 0 | 0 | 0 | 0 | 0.21 | 0 | 0 | 0 | 0 | 0 | X |

#### 5.3.6.5 Induced Analysis

Induced analysis was used to summarize the findings and provide practical recommendations to the stakeholders. Based upon the three previously mentioned types of analysis, the team induced that the UAS program is in the center of disaster information transport and can most frequently determine the information flow of disaster management. It is easiest to obtain disaster information from some supporting agencies, such as the state departments of transportation, environment quality, public safety, and the local council of government. Moreover, four groups of disaster management agencies are categorized, and each of these groups will have different disaster management functions with some needing more communications. In addition, the FAA and local ATC have the strongest connection and will need the most frequent communication.

### *5.3.7 Managerial Insights*

Utilizing the induced analysis, the team derived the managerial insights and provide practical recommendations to stakeholders. Below are the project team's suggestions:

1) As the UAS program is the center of information flow, it is highly recommended to have a specialist dealing with information transport. This specialist should have efficient connections with different disaster management agencies and the ability to deliver timely and accurate information.
2) As the 12 disaster management agencies have been categorized into four groups: approval and coordination group, supporting group, operation and response group, and social media group, highlighting the major function for each of group is recommended. For example, the UAS program belongs to the operation and response group, therefore, it is best to focus on the search and rescue aspects during the disaster rather than social affairs.
3) It will be easy for supporting group agencies, such as state departments of transportation, environment quality, public safety, and the local council of government, to obtain disaster information. Therefore, it is recommended they link with corresponding agencies. For example, the state department of transportation should link directly with the UAS program. There is no need for it to make multiple connections for disaster management.
4) For some of the most frequent connections, such as FAA/local ATC, the creation of a hotline for disaster management and coordination is recommended.

### *5.3.8 Observations and Recommendations*

Many qualitative observations were made during the data collection process that cannot be conveyed by the MBSE models and analysis. This section describes these observations and provides general insight.

#### 5.3.8.1 UAS Special Government Interest Requests for Disaster Response

A unique aspect to public safety UAS operations in the NAS is the ability to coordinate airspace for disaster response activities. The SGI process allows for addendums to 14 CFR Part 91 and Part 107 operations for significant and urgent emergency operations or law enforcement activities. According to FAA Order JO 7200.23B, the SGI addendum request process is managed by the FAA's ATM Systems Operations Security. Systems Operations Security is responsible for air traffic facilities coordination, national security operations, and safety and efficiency impacts on the NAS. The SOSC in Northern Virginia manages the SGI process program for UAS emergency operations by granting waivers and authorizations as Certificate of Waiver or Authorization (COA) addendums, modifications, and CFR Part 107 authorizations.

The SOSC is staffed with highly experienced FAA air traffic controllers who maintain a 24/7 response. Originally tasked to assist with post-disaster airspace coordination after the Hurricane Katrina Gulf Coast landfall in 2005, the SOSC previously managed disaster response requests by amending existing COAs with "emergency" COAs. Emergency COAs allowed access to controlled, restricted, or prohibited airspace and allowed expanded airspace operations not defined on the existing COAs.

The SGI process was established near the time of Hurricane Harvey's 2017 landfall and replaced the Emergency COA process and included more operators and broader categories of flight operations. The SGI process's intent was to expand, rather than restrict, access to airspace for both public and non-public aircraft operations if it is safe to do so. Approximately 60% to 70% of SGI requests are public operators, including first responders, law enforcement, and fire response. Non-public operators make up the remaining SGI requests, including utility companies, media, and insurance companies. Infrastructure inspections by utility companies represent the largest portion of non-public aircraft entity utilizing SGIs. However, according to FAA Order JO 7210.3CC, SGI requested operations must be flown by a public entity or sponsored/supported by a public entity in direct support of emergency operations, response, relief, or recovery benefitting the public. Most of the day-to-day operations of SOSC watch standers is in support of disaster response, law enforcement, or emergency operations at the local, state, and national level.

The SGI process requires that the requesting disaster response entity have an active COA or CFR Part 107 certification. Of the current requestors, approximately 75% have an existing COA or are in the process of applying for one. Nearly all public entity COA holders also have Part 107 certificates. Having both an existing COA and a Part 107 certificate allows more flexibility in the request process since the SGI approval can be either a COA addendum or Part 107 addendum. In some cases, the SGI requester may not have a copy of existing COA to submit to the SOSC due to the emergency response timeframe, and a Part 107 addendum becomes the quickest means of FAA airspace or operational approval. The SOSC watch standers will also provide guidance during the SGI addendum request process if the waiver authorization falls outside the requester's existing COA jurisdiction.

The SGI addendum process is initiated by submitting the Emergency Operation Request Form as described in Section 5 of FAA Order JO 7210.3CC (FAA, 2021). The Emergency Operation Request Form, titled FAA Request Form for Expedited SGI Waiver or Authorization for UAS Operation, is available at https://www.faa.gov/uas/advanced_operations/emergency_situations/. The request form is normally emailed to the FAA and followed up by contacting the SOSC at (202) 267-8276 to confirm receipt. Much of the form can be completed beforehand to expedite the submission. Once the SGI addendum request is received, the SOSC will review the request and determine the necessary amendments to existing COAs and CFR Part 107 authorization/waivers. The SOSC will also coordinate the airspace with local ATC and determine if any further airspace mitigations are needed, and also if the Remote Pilot in Command (RPIC) needs to contact local ATC before and after the UAS operations. A COA addendum or a CFR Part 107 authorization/waiver will be issued by the SOSC. In time-critical emergency response situations, the SOSC can be called before the request is submitted by providing the following information: 1) UAS flight location; 2) desired altitude; 3) UAS operations contact information; and 4) duration of the operation. A verbal SGI addendum authorization can be issued and followed up by written confirmation. Approximately 5-10% of the SGI addendums are granted verbally by SOSC watch standers, and verbal authorization is normally associated with time-critical operations, such as missing persons, traffic incidents, and arrest warrants outside normal working hours.

The SGI addendum process represents approximately 50% of the SOSC staff workload and continues increasing as more public safety entities utilize UAS for disaster and emergency response. The SOSC management constantly monitors the number of SGI addendums received for determining future 24/7 operations staffing decisions. Disaster response airspeed coordination efficiencies are often a direct result of public safety entities' recurring usage of the SGI addendum process and their familiarity with the addendum request process requirements. SOSC management believes the SGI addendum request process is working smoothly and efficiently, and their willingness to pursue outreach opportunities for SGI addendum awareness continues to improve collaboration and teamwork between the FAA and disaster response entities.

#### 5.3.8.2 FEMA UAS/Remote Sensing Coordinator, FEMA Region 4

The Region 4 UAS/Remote Sensing Coordinator of FEMA was interviewed to provide the federal context to a disaster. FEMA Region 4 is unique in that their UAS Coordination program is the most progressive and extended from all the other regions. As technology progresses, the approach taken by the Region 4 UAS/Remote Sensing Coordinator is ever evolving.

This discussion focused on generalities of disaster response as no disaster is the same. FEMA has no UAS assets of its own, so the way it handles the coordination of state and local assets depends heavily on the state(s) where the disaster occurred. Because this interview was not specific to one disaster, it was not modeled. However, a summary of FEMA Region 4’s coordination process is provided for greater context.

Once a disaster receives a presidential declaration, a FEMA regional response center is stood up to handle federal resources. Generally, each state has its own Emergency Operations Center (EOC) where the state Emergency Management Agency (EMA) handles its own state’s resources. An incident management assistance team and a liaison officer of a FEMA Integration Team will be sent to the state EOC for emergency support functions. These personnel coordinate and share data between the state EOC and the FEMA response center through daily calls.

Airspace coordination varies state to state, but, typically, an Air Operations Branch (AOB) is managed at the state level either by state officials, the local national guard, or another appropriate entity. Generally, the AOB operates out of the state’s EOC. The AOB manages both crewed and uncrewed operations, and, for FEMA region 4, there is an air boss specific to uncrewed operations. The AOB keeps track of crewed aircraft first and ensures that uncrewed aircraft are not interfering with Life Safety missions performed by the crewed assets. For a variety of safety reasons, uncrewed aircraft are generally not deployed during this stage of disaster response. Once the Life Safety missions finish, the Situational Awareness stage is initiated, and the airspace coordination between FEMA Region 4’s Remote Sensing Cell and other entities begins.

At the Situational Awareness stage, the remote sensing cell interacts with state partners, such as fire and police, the media, power companies, insurance companies, and the FAA, to discuss airspace coordination. Factors considered include, SGIs, current TFRs, the TFR holders, locations of life safety missions underway, and the particular air boss. However, the Remote Sensing Cell does not coordinate, at this stage, what local police and fire do. During the Situational Awareness stage, each entity operates within its own guidelines and directives. At this point, a presidential declaration has not been made, and information gathering continues. This stage eventually transitions into Response and Recovery.

Response and Recovery is the final stage, and a presidential declaration is made to release federal funding and resources to affected states. During the response and recovery stage, a collaborative collection plan is employed by FEMA. This plan helps coordinate resources and data between FEMA and the other entities.

#### 5.3.8.3 Temporary Flight Restrictions for Disaster Events

TFRs are a type of Notices to Airmen (NOTAM) issued by the FAA to restrict flight operations within a defined area in U.S. airspace for protecting people or property in the air or on the ground. ATC air traffic managers throughout the U.S. are responsible for coordinating TFRs within their airspace jurisdiction. A TFR can be issued for disaster and hazard situations to protect people or property, provide a safe environment for relief aircraft, and prevent unsafe flight congestion in airspace over an incident or event. FAA air traffic managers accept requests for and, if warranted, set up disaster response TFRs in accordance with provisions found in 14 CFR Part 91.137. Local ATC facilities serve as the TFR's primary coordinators for communication between emergency response agencies and "affected" aircraft. Though crewed and uncrewed aircraft may not fly within a TFR-designated area – except under direction of the official coordinating the emergency response activities – many times disaster events are inundated with crewed and uncrewed aircraft not involved in relief activities. The response effort in a recent south Florida condominium collapse experienced approximately 55 non-compliant uncrewed aircraft, crewed fixed-wing, and crewed rotary-wing operating in the disaster area airspace. Thankfully, many of the non-compliant aircraft were identified by disaster response aircraft for FAA review and legal action.

Some TFRs are unique to UAS disaster response. BVLOS TFRs extend the visual range of the UAS flight personnel and allow for UAS flight crews to cover larger areas for response activities. BLVOS TFRs are granted by the FAA's SOSC via SGI addendum requests. In addition, ATC air traffic managers notify the SOSC when a 14 CFR Part 91.137 TFR is issued for hazards associated with incidents on the ground and media interest regarding the TFR. Watch standers in the SOSC also ensure coordination between TFR points of contact and the RPIC identified in the SGI addendum.

Even though TFRs are common for disaster response, many times TFRs are not properly set up to ensure safe operations between crewed and uncrewed aircraft. The establishment of a TFR must not prevent response activities for the disaster but assist by providing improved traffic separation and airspace coordination. Block airspace TFRs for crewed and uncrewed disaster response aircraft should start at the surface and extend upward to the appropriate altitude for response activities. Flight restricted TFR airspace starting above the surface only encourages non-compliant crewed and uncrewed operators not involved in hazard relief activities to descend to an altitude below the TFR for sight-seeing purposes, as experienced in the Hurricane Michael response TFR over the Florida Gulf Coast from 200 ft to 3000 ft AGL. In addition, disaster event TFRs must be large enough to allow proper response but small enough not to disrupt the flow of air traffic. The most effective method of managing a disaster event TFR is using an airborne on-scene coordinator with proper communication equipment. A recent successful example was the use of U.S. Customs and Border Protection fixed-wing aircraft for TFR on-scene aircraft traffic management and monitoring.

The FAA Advisory Circular (AC) on TFRs and Flight Limitations, AC No. 91-63D, was an update to 91-63C published earlier in 2004. The use of UAS for disaster response has changed dramatically since the introduction of 14 CFR Part 107 and growth of UAS flight operations by local, regional, state, and federal public safety agencies. The FAA's TFR AC should be updated to include best coordination practices for crewed and uncrewed aircraft response.

### *5.3.9 Conclusion*

The Model Based Systems Engineering toolset software was chosen to model three different diagrams for several different types of disasters. The BDD identified the relationship between the organizations and responders involved in the disaster response. The UCD represents dataflow topics and interface between organizations and responders during the disaster. The AD shows the control flow of a disaster response from the perspective of the critical task

For each modeled disaster, the connection information between entities was gathered and placed into a weighted graph. The weighted graphs were used in three types of analyses: centrality analysis, community detection analysis, and connectivity analysis. From the results of these analysis, an induced analysis was used to developed managerial recommendations for disaster response agencies.

From the induced analysis, the UAS program is the center of disaster information and frequently determines the flow of information during disaster management. State departments such as the department of transportation or environment quality and public safety are the easiest to obtain disaster information from. The FAA and local ATC have the strongest connection to the UAS program and requires the most frequent amount of communication. As the UAS program is the center of information flow, a specialist whose task is to communicate with other agencies is highly recommended. State departments should connect with the UAS program’s communication specialist directly.

## 5.4 Use Cases and Usage Challenges

An effort was put forward to formalize and tabulate the many possible ways in which UAS might be employed in a variety of disaster situations. The team looked at the timeframes prior to an event, during the event, and after the event to document a broad variety of possible involvements. The research continued in postulating the kinds of aircraft and payloads that would likely be appropriate for each scenario. Use cases evaluated include wildland fires, oil spills, pandemic, earthquake, volcano, hurricane, flooding, tornado, terrorism, nuclear dispersion, and train derailment. A separate analysis looked at the broad subject of medical supply and communications among first responders.

For each unique scenario, the team defined several questions or issues that would be considered in the Operational Risk Assessment. These include:

- Is the use case one of preparedness, response, or follow-up?
- What type of flight is involved?
- Is the mission within or beyond line of sight?
- What type of UAS will most likely be used? (Fixed wing, multirotor, hybrid)
- What design considerations might factor into the choice of a UAS?
- What candidate UAS might be considered?
- What might constitute a typical flight scenario?
- What kinds of payloads are involved?
- What data is to be collected?
- What data products will be produced and how are they likely to be used?
- Special notes to supplant the information described above.
- What are the benefits to be derived from using UAS in the specified situation?

The result of this work is presented in detail in Appendix E.

### 5.5 Safety and Operational Risk Assessment (ORA)

An ORA supports the analysis of a CONOP to identify if mitigation actions are in place to conduct UAS missions with an acceptable level of risk

An ORA should include specific details to support the authorization of the CONOP for the specific UAS mission. The ORA follows a consistent approach to assess the acceptability of risks and mitigation procedures for mission safety. Mitigation procedures for each risk outlined in an ORA provide details on the best strategy and mitigation action to reduce risk to a level acceptable for safe operations. Mitigation procedures ensure acceptable risk levels for the proposed operations. FAA severity and likelihood decision matrices are used to assess the hazard risk level for operations and the adjusted risk when the mitigation measure is in place.

The methodology of applying the ORA with the CONOP focuses on establishing, with a level of confidence, that the operations can be conducted with an acceptable level of risk. The evaluation process centers on assessing the ground and air risk along with any risk placed on critical infrastructure in and around the mission location. The CONOP is evaluated against the defined hazards in the ORA to check that the CONOP includes mitigation procedures to ensure that the severity and likelihood of the hazard impacting flight operations are at a minimum.

In building an ORA, the hazards that can impact flight operations are collated into five categories that focus on adverse operating conditions, external systems, human factors, the UAS itself, and cyber threats to UAS operations.

The Safety and Operational Risk Assessment performed as part of this research is described in detail in Appendix E.

### 5.6 Concepts of Operations (CONOPS)

A synopsis of each CONOPS is presented in this section. The details of each CONOPS are presented in Attachments 1-10. The summaries are subdivided into 4 subtopics: Mission Purpose/Objectives; Mission Procedures/Approach; Mission Results; and Mission Milestones. These are defined as follows:

- Mission Purpose/Objectives: Provide details on the aims and objectives of the UAS flights and the specific disaster preparedness and/or response event that is being supported. Highlight the benefits that the collected outcomes from the flights will provide for the decision support teams preparing for and/or responding to the specific disaster event.
- Mission Procedures/Approach: Provide a summary of the flight operations that will occur during the disaster preparedness and/or response support. Give details on the number of aircraft and type [large v small and/or VTOL v fixed wing]. Include an overview per aircraft on the sensors. If multiple UAS to be used to support needs of response to disaster event, then include a timeline of the different operations and if there is overlap between the aircraft flights. Per flight, provide details on operational details such as VLOS or BVLOS and if COA or waivers are reviewed.
- Mission Results: Provide details on the results that will be produced from the UAS operations to support the disaster preparedness and/or response. Include a list of the data products to be produced and if near real-time or post-flight.

- Mission Milestones: Provide the milestones that will be accomplished during the flights that represent a successful mission. These can be assessed and evaluated during any post-operations discussions and any issues defined that prevented the missions and flight operations accomplishing these milestones. These metrics also clearly define the opportunities that UAS provide to the disaster preparedness and response community and how it supports their decision-making process.

### *5.6.1 CONOPS Summary – Airport Terrorism*

This CONOPS represents a terrorism event at Huntsville, Alabama International Airport (HSV). It will include surveillance of ongoing events and disruption and counter measures to the attack.

#### 5.6.1.1 Airport Terrorism Mission Purpose/Objectives

The purpose is to accurately portray a terrorism event at the Huntsville, Alabama airport. The team will use a report of a terrorist event and will use airborne assets, as they need eyes and communications on the event from a higher altitude. A fixed location aerial asset shall be located in such a position that it will enable visual contact and communications on the full extent of the airport. Smaller UAS will be placed in various locations in and around the airport to enable quick response to terrorist incursions.

Goals: Large UAS will keep continued eyes and communications on the airport [runways and infrastructure] to get data to an emergency management operations center. Local small UAS Part 107 pilots will respond to specific requests and provide data. Tethered small UAS will be established at the airport with all permissions in place. A goal will be to demonstrate that the mobile small UAS can respond to the needs of an emergency management operations center and provide data on the event. Counter small UAS will demonstrate their ability to react to airborne terrorism assets and ensure the safety of the airport and all infrastructure. The demonstration will show communication between the multiple UAS flight teams and prove that the emergency management operations center is able to communicate with pilots in command and get tethered UAS to move their field of view. Another goal is to get mobile small UAS to move to the area of impact and to get counter UAS to react to hostile airborne asset. The team will also launch a large UAS to provide data feedback to the emergency management operations center.

#### 5.6.1.2 Airport Terrorism Mission Procedures/Approach

Objectives: A large UAS with real-time data to Ground Control Station (GCS) and onto operations center is used to detect and provide airborne surveillance from above the Terrorism event. Tethered small UAS #1 at the airport terminal gains eyes and communications on the event from a fixed location and turns on a dedicated communications hub over specific channels only for ground operations use so that emergency management services can put in phone lock to prevent terrorist events communications network. Small UAS #2 is flown into the TFR area to provide mobile eyes and communications on the event at low altitudes. This will show it responds to needs of operations center and focuses on target areas and gets high resolution feeds back to the operations center . Small UAS #3 is counter UAS and the mission shows it can respond to hostile airborne assets to the event. Intent is to show that it can move in to prevent impact from these assets and remove them as a hazard. Small UAS #3 can move supplies from outside airport boundaries into the hazard zone without putting ground personnel at risk and to support those impacted by the hazard. This exercise will evaluate how small UAS missions can respond to lUAS operations and data analysis. It will evaluate how local 107 pilots can respond to needs of State and/or City agencies. It also will evaluate how tethered small UAS #1 can provide eyes and communications on events as well as act as a communications hub.

#### 5.6.1.3 Airport Terrorism Mission Results

Observations: Recording of full extent of the event from a large UAS whose flight pattern aims to provide continued data collection. At least three small UAS are used. Small UAS #1 is tethered to the airport terminal to provide a fixed location and electro-optical/thermal data with a pointable payload. Small UAS #2 is a mobile system with electro-optical/thermal payload and flown at low altitude around the airport to get eyes and communications on the event. Small UAS #3 provides counter UAS capabilities and can react to other airborne assets. If small UAS #3 is used, then the team will need another UAS in the air to support counter UAS capabilities for the response. Small UAS #3 provides delivery capability to get supplies into hazard zone [both to support ground ops and those impacted by the event].

Real-time Mission Products will include:

- Large UAS: Electro-optical/thermal video feeds back to emergency management operations center.
- Small UAS #1: Electro-optical/thermal videos and open communication channels for others in response to use.
- Small UAS #2: Electro-Optical/thermal videos back to emergency management operations center.
- Small UAS #3: Electro-optical feeds back to emergency management operations center.
- Data from all UAS displayed in geospatial interface to superimpose on other available data from state, federal, and local agencies.

Post-Mission [fast response] Products: Nothing specific as critical aspects of the response is to get eyes and communications on the event, provide the response team its own communication hub, and small UAS to respond to hostile airborne assets.

#### 5.6.1.4 Airport Terrorism Mission Milestones

Outcomes/Actionable Intelligence:

- Large UAS successful mission and pushes data back to ground to build maps and videos of events
- Small UAS #1 airborne and provides continued eyes and communications
- Small UAS #1 communications used by ground teams to communicate with emergency management operations center and others
- Small UAS #2 mission to provide low altitude data on ground hazards
- Small UAS #3 able to thwart off hostile airborne assets
- Small UAS #3 able to provide delivered to ground teams with critical supplies
- All UAS provide electro-optical/thermal data that can be processed into products at the need of emergency management operations center such as 3D models (electro-optical and thermal overlay) of impacted infrastructure, location of hostiles.

Metrics of success:

- Large UAS streams data back to the incident center to support assessment of full extent

- Small UAS #1 streams back data to emergency management operations center and can move field of view based on needs
- Small UAS #1 provides a communications hub so emergency management operations center can limit other communications
- Small UAS #2 moves to locations needed by emergency management operations center on the ongoing disaster
- Small UAS #3 responds to hostile airborne assets; limits impact or removes from airport TFR
- Small UAS #3 time optimized to delivery supplies to ops team or impacted personnel while waiting to provide counter drone support
- Safe flight operations with three small UAS and one large UAS operating and data streaming back
- All small UAS flew under Part 107 and VLOS to EVLOS is maintained.

### *5.6.2 CONOPS Summary – Earthquake & Tsunami*

Large earthquake in South-Central Alaska with Tsunami warning and need to map inundation to Seward region.

#### 5.6.2.1 Earthquake & Tsunami Mission Purpose/Objectives

Purpose: Large earthquake in South Central Alaska that impacts Anchorage to Palmer region; Tsunami warning and then inundation of coastline and impacts Seward; Bridge collapse along highway from Anchorage to Palmer and need to map.

Goals: Large UAS up and mapping impacted region to get data to emergency management operations center. Small UAS Part 107 pilots respond and provide data of impacted regions [Bridge and City of Seward] to show that they can be useful during disaster without needing to send EMs from Anchorage until needed. Small UAS support analysis of local infrastructure and safety assessment.

Objectives: Large UAS with real-time data to GCS and onto emergency management operations center used to detect bridge hazard and to target local finer scale mapping of impacted infrastructure. Small UAS #1 responds to and collects data for viewing at emergency management operations center. Small UAS #2 provided by Seward-based emergency management operations approved Part 107 pilot collects data over impacted areas and provides data back to local GCS and emergency response as well as feeds to State emergency management operations center. Evaluate how small UAS missions can respond to large UAS operations and data analysis. Evaluate how local 107 pilots can respond to needs of State and/or City agencies. Evaluate how local 107 pilots respond to Tsunami warnings and reports to map regions and feed data back to the State emergency management operations center.

#### 5.6.2.2 Earthquake & Tsunami Mission Procedures/Approach

Large UAS: High Altitude observations over disaster area are characterized as follows:

- Early morning take-off from Anchorage
- (BVLOS operations
- Flown from runway to the traverse up to Palmer
- Route defined to cover main road networks and communities

- Day of flying to reach site and provide high altitude eyes on disaster
- Visual Flight Rules (VFR)/Instrument Flight Rules (IFR) conditions as will be BVLOS
- Weather conditions: Pre-flight and during flight

Small UAS #1: Tsunami Inundation impact in Seward operations will include:

- Locally based Pilot approved for emergency management operations center
- Part 107 waiver and SGI waiver
- Fly VLOS or Extended-VLOS (EVLOS) under VFR conditions
- Weather conditions: Pre-flight and during flight
- Map the extent of impact to community and if possible, further across Bay

Small UAS #2: Bridge along highway between Anchorage and Palmer will feature:

- Locally based Pilot approved by emergency management operations center
- Pattern defined to map extent of damage seen in large UAS and any ground reports
- VLOS with Part 107 waiver if needed based on time of day/location/altitude
- VFR conditions
- Weather conditions: Pre-flight and during flight

#### 5.6.2.3 Earthquake & Tsunami Mission Results

Observations from this mission will include:

- Recording of full extent of the damage of the earthquake to infrastructure and transportation networks across South Central Alaska.
- Data feeds back to emergency management operations center and determines there is a collapsed bridge on the highway that needs local small UAS mapping.
- Secondary tsunami warning that predicts inundation along the South-Central coastline.
- Seward reports Tsunami and local small UAS operations, maps damage, and feeds data back to their GCS as well as State operations center.

Real-time Mission Products include:

- Electro-optical visible and where possible thermal data feeds back to GCS and operations center from all three UAS.
- Data displayed in geospatial interface to superimpose on other available data from state, federal, and local agencies.

Post-Mission [fast response] Products will include:

- Large UAS: Geospatial located video feeds to show field of view to analyze for impact to infrastructure.
- Small UAS #1 at Seward: Optical videos of impact to the community and coastline and where possible thermal data.
- Surface and three-dimensional (3D) models where structure from motion (SfM) is possible to assess damage.
- Small UAS #2 at bridge: Orthomosaics in optical wavelengths of bridge and surrounding area as 3D models where SfM is possible to assess damage.

#### 5.6.2.4 Earthquake & Tsunami Mission Milestones

Outcomes/Actionable Intelligence are anticipated to include:

- Large UAS [Higher altitude eyes and coms on disaster] - Adaptable mission will map the full extent of the disaster. Electro-optical video data feedback to GCS will be piped into emergency management operations center. GCS team is in communications with emergency management operations center and then small UAS #1 team for bridge inspection.
- Small UAS #1 [Bridge] - Mission is readied and flown once bridge is seen in large UAS data and flight had adapted to focus on the collapsed bridge. Electro-optical video feed back to pilot in command is piped into the emergency management operations center. 3D rendering of the bridge is made available soon after mission is flown. Field of view (FOV) of electro-optical camera will be seen in emergency management operations center so they can adapt flight as their needs dictate.
- Small UAS #2 [Seward for Tsunami] - Mission is readied once reports of Tsunami have impacted the community. Electro-optical and thermal video feeds back to PIC and are piped into the emergency management operations center. PIC is able to adapt routes at the needs of local emergency management and ground teams to support operations. 3D rendering of the community will be made available after flight lands and data is processed. Thermal imagery will be overlaid on the 3D model of the landscape.

Metrics of success include:

- Large UAS streams data back to the incident center to support assessment of full extent
- Small UAS #1 streams back data to support those on ground to assess Tsunami Inundation
- Small UAS #2 maps bridge and gets real-time videos back to the emergency management operations center
- Small UAS #2 PIC responds to commands from the incident center on where obs. are needed
- Safe flight operations with two small UAS operating and data streaming back
- Both small UAS flew under Part 107 and VLOS is maintained
- Local Part 107 small UAS pilots respond to requests and data back to the emergency management operations center.

### *5.6.3 CONOPS Summary – Hurricane, Tornado, Flooding*

A hurricane is passing from Gulf of Mexico into Louisiana and makes landfall around New Orleans with accompanying tornadoes. Significant building damage and extensive flooding is observed along with a need for air support for search and rescue operations.

#### 5.6.3.1 Hurricane, Tornado, Flooding Mission Purpose/Objectives

Purpose of this mission: To respond to a significant hurricane (category 4) passing onto land near New Orleans with subsequent tornadoes impacting the landscape and communities and then post-event extensive flood waters that continue to impact surrounding communities. Also, a lack of cell-coverage requires airborne communications to support ground teams.

Goals of this mission:

- Large UAS providing long endurance eyes and communications over the impacted area from high altitude.
- Small UAS #1 will be tethered and at fixed location to provide communications hub for ground operations as well as additional electro-optical/thermal video feed of the area.
- Small UAS #2 with an electro-optical and thermal payload that can get close to buildings to support ground SAR [SAR for survivors; Short campaigns; Targeted to support ground operations].
- Small UAS #3 with an electro-optical and thermal payload that can focus on collected data on at-risk buildings so that ground teams can assess if there is any risk of further damage/collapse.
- Small UAS #4 will have electro-optical and visible-near infrared payload to fly around the flooded areas to assess extent of water flooding and also over time assess the water levels as they recede.

Objectives of this mission:

- Large UAS will provide real-time data to GCS and onto emergency management operations center that is used to provide airborne surveillance from above the disaster zone.
- Tethered small UAS #1 in the disaster zone gains eyes and communications on the event from a fixed location and turns on a dedicated communications hub over specific channels only for ground operations use.
- Small UAS #2 is flown manually, and the flight pattern adapts based on the ground team SAR needs. Small UAS #2 will take-off and land from several locations as the ground team makes requests.
- Small UAS #3 is flown to provide data on the at-risk infrastructure within the disaster zone. As with small UAS #2, small UAS#3 will be flown manually with take-off and landing locations as defined by the needs of the ground team.
- Small UAS #4 is flown on predetermined routes based on observations that have been analyzed by the emergency management operations center and collected by the large UAS. Small UAS #4 will fly with VLOS permissions in place and also with capability to adapt flight plans based on needs of the emergency management operations center to map the water levels.
- Evaluate how small UAS missions can respond to large UAS operations and data analysis.
- Evaluate how local Part 107 qualified pilots can respond to needs of State and/or City agencies.
- Evaluate how tethered small UAS #1 can provide eyes and communications on events as well as act as a communications hub.

#### 5.6.3.2 Hurricane, Tornado, Flooding Mission Procedures/Approach

- Large UAS: Rapid response will take-off from Huntsville [HSV] airport - 3 hr. flight time to disaster zone.
- BVLOS operations, Flown from nearby runway will then have holding pattern above disaster zone.
- Multiple hours of flying will provide high altitude eyes and communications on disaster.

- VFR/IFR conditions are assumed allowing BVLOS flight - able to fly in full range of conditions.
- Small UAS #1: Tethered sUAS is fixed to one location within the disaster zone.
- VLOS operations, Part 107 waiver and SGI waiver are assumed to prevail. [Might have different needs as tethered system.]
- Eyes and communications are focused on infrastructure with pointable electro-optical/thermal sensors.
- Provides response only communications hub, powered through tether so can stay airborne for extended period and/or whole event
- Small UAS #2: Performs short pop-up flights during disaster response
- Manual small UAS: Provides search and rescue electro-optical/thermal capability to support ground teams.
- Flown from multiple locations answering the needs of SAR teams.
- Performs VLOS flights with Part 107 or SGI waiver.
- Operates in VFR conditions [IFR if event limits visual observer from keeping VLOS].
- Small UAS #3: Conducts short pop-up flights during disaster response.
- Manual small UAS: Conducts building safety assessment using electro-optical/thermal to support ground teams. Flown from multiple locations at the needs of ground teams and emergency management operations center. VLOS with Part 107 or SGI waiver
- Small UAS #4: Long endurance flights to map the extent of the flooding
- Pre-defined routes based on large UAS data with ability to manually fly at needs of emergency management operations center
- Electro-optical with visible-near infrared sensor, VLOS operations with capability and permissions to extend to BVLOS, if needed
- VFR conditions [IFR if event limits VO from keeping VLOS]

#### 5.6.3.3 Hurricane, Tornado, Flooding Mission Results

Observations:

- Recording of full extent of the event from a large UAS whose flight pattern aims to provide continued data collection.
- At least four small UAS used.
- Small UAS #1 is tethered to GCS and placed within the disaster area to provide a fixed location for communications and electro-optical/thermal data with a pointable payload.
- Small UAS #2 is a mobile system with electro-optical/thermal payload and flown at low altitude to support ground teams as they perform SAR.
- Small UAS #3 provides electro-optical/thermal video feeds of at-risk infrastructure so that the ground teams and emergency management operations center can assess if they are safe or if further damage is possible.
- Small UAS #4 will provide electro-optical and visible-near infrared observations of the flooded area whose flight pattern will be defined based on the data from the large UAS. Small UAS #4 may be flown manually, if required to map the flooded areas.

Real-time Mission Products:

- Large UAS - Electro-optical/thermal video feeds back to emergency management operations center.
- Small UAS #1: Electro-optical/thermal videos and open communication channels for others in response to use.
- Small UAS #2: Electro-optical/thermal videos back to emergency management operations center and SAR ground teams.
- Small UAS #3: Electro-optical/thermal videos back to emergency management operations center and infrastructure inspection ground teams.
- Small UAS #4: Electro-optical and visible-near infared video feeds back to emergency management operations center. Data from all UAS are displayed in a geospatial interface to superimpose on other available data from state, federal, and local agencies.

Post-Mission [fast response] Products:

- Mosaicked maps of the full extent of the disaster from the large UAS,
- 3D constructed dataset from small UAS #2 of at-risk infrastructure with thermal infrared superimposed,
- Mosaicked maps of the water extent from small UAS #4 with possible visible (electro-optical) and visible-near infrared comparisons.

#### 5.6.3.4 Hurricane, Tornado, Flooding Mission Milestones

Outcomes/Actionable Intelligence:

- Large UAS completes successful mission and pushes data back to ground to build maps and videos of events,
- Small UAS #3 successfully stays airborne and acts as a communications hub with tethered system for power and data transfer,
- Small UAS #2 feeds real-time electro-optical and thermal infrared video feeds to ground operations to perform SAR,
- Small UAS #3 feeds electro-optical video feeds back to ground operations to evaluate buildings impacted by tornado and hurricane,
- Small UAS #2 & #3 fly defined patterns and manually move to locations needed by the ground team and emergency management lead,
- Small UAS #4 successfully produces data to build maps of flooded areas,
- Small UAS #4 supports ground teams to evaluate water extent and impact on communities and buildings,
- Small UAS #4 delivers real-time feeds of flooding extent and post-production of mosaicked georectified maps

Metrics of success:

- Large UAS streams data back to the incident center to support assessment of full extent,
- Small UAS #1 provides a long-term communications hub for ground teams where cell tower coverage is lacking,
- Small UAS #2 streams back electro-optical data to operations center and can move field of view on needs for ground teams SAR,

- Small UAS #3 moves to locations needed for the ongoing disaster and where buildings need inspection,
- Small UAS #2 maps buildings as defined by ground teams,
- Small UAS #4 produced real-time needs to assess flooding and where to send ground teams to minimize impact and to at-risk areas,
- Small UAS #1 - #3 fly under Part 107 and VLOS to EVLOS is maintained,
- Large UAS and Small UAS #4 receive BVLOS permissions.

### *5.6.4 CONOPS Summary – Oil Spill*

Oil Spill from terminal onto land and ocean.

#### 5.6.4.1 Oil Spill Mission Purpose/Objectives

Purpose: Oil Spill from Valdez Terminal onto local land and across into Port of Valdez Harbor.

Goals: Record the spill from terminal with electro-optical videos and where possible multispectral images. Small UAS mission at lower altitude over terminal. Small UAS mission off boat to assess spill extent over the ocean and Port of Valdez. Large UAS at higher altitudes to assess full extent and if possible, SAR data to detect spill on ocean surface.

Objectives: Large UAS with real-time data and possible machine learning from search and rescue data. Small UAS at terminal to feed optical video to emergency command center and multispectral images. Second small UAS off boat to analyze extent over ocean and feed data back to the emergency command center. Evaluate how to work with two small UAS in the same airspace. One will have focused analysis at the terminal, while the second will be moving based on the oil extent and finding the edge of the oil. Also, may be using repellent to burn off oil in-situ from remote systems on UAS.

#### 5.6.4.2 Oil Spill Mission Procedures/Approach

Large UAS: BVLOS operations over disaster

- Early morning take-off from Anchorage or Kenai
- Flown from runway to the traverse up Port of Valdez Bay towards terminal
- Day of flying to reach site and provide high altitude eyes on disaster
- VFR/IFR conditions as will be BVLOS and traveled from airport to Valdez

Small UAS #1: Terminal mapping

- Part 107 waiver and SGI waiver
- Option 1: May need to fly across Bay from Valdez - if so then BVLOS or extended line of sight (EVLOS)
- Option 2: Flown from near terminal and so would be visual line of sight (VLOS)
- Flown in the TFR region - match when large UAS overhead and small UAS over ocean
- VFR conditions
- Map the extent of impact to terminal and multispectral spill over land

Small UAS #2: Flown from boat in the Port of Valdez Bay

- Routine pattern or defined by emergency team to map extent of oil drifting in ocean
- Option 1: Electro-optical and multispectral to map oil spill extent

- [Note video will be used over ocean and SfM mapping near coastlines where stitching techniques have improved performance]
- Option 2: Carry repellant to burn off oil in-situ
- Time of flights to match large UAS observations
- VLOS with Part 107 waiver if needed based on time of day/location/altitude
- VFR conditions

#### 5.6.4.3 Oil Spill Mission Results

Observations: Recording any continued spillage from the terminal; understanding of the extent of the land-based spillage and required clean up. Extent of the spill into the harbor: include where it is heading, clean up area of focus, and if extents across to coast on other side of bay and into City off Valdez. Small UAS will have electro-optical and multispectral sensors. Large UAS will collect -electro-optical, thermal and if possible, SAR. Potential for small UAS to place repellent onto oil and then be able to burn it off in-situ from UAS.

Products: Small UAS #1: Electro-optical videos of terminal and multispectral images of oil extent on land. Orthomosaics in optical wavelengths of terminal once spill ends as well as 3D models where structure from motion is possible to assess damage to the terminal. Small UAS #2: Electro-optical videos of ocean extent of oil spill and where possible multispectral or thermal data. Large UAS: Electro-optical videos of the full extent of the disaster and where possible SAR maps of the oil on the ocean and land to compare to optical data.

#### 5.6.4.4 Oil Spill Mission Milestones

Outcomes/Actionable Intelligence

- Large UAS: Electro-optical data from higher altitude
    - Real-time streamed back to operations center or post-processed and displayed in visualization tool
    - Large UAS operations to get data of full extent of disaster to operations center to determine locations for small UAS #1 and #2
    - Small UAS #1: True Color and near-infrared with electro-optical video data to map terminal area and produce orthomosaic map of landscape around terminal to determine if any spillage.
    - Small UAS #1 flight to build 3D model of the terminal area; Displayed in visualization tool to support ground ops team
- Small UAS #2 [Option 1: Mapping]
    - Ship launch and recovery to fly small UAS over impacted area seen in large UAS data
    - Production of orthomosaic that shows any evidence of oil on ocean surface and coastline
- Small UAS #2 [Option 2: Ignite oil in-situ]
    - Ship launch and recovery to fly small UAS over impacted area seen in large UAS data
    - Placement of repellent on oil surface and ignite of oil on ocean surface
    - Electro-optical data review of oil removal

Metrics of success

- Large UAS streams data back to the incident center to support assessment of full extent.
- Small UAS #1 streams back data to support those on ground to mitigate terminal hazards.
- Small UAS #2 maps extent of oil with routes adapted to find spread in oceanic environment
- Small UAS #2 pilot in command responds to commands from the incident center on where observations are needed.
- Small UAS #2, Option 2, places retardant onto oil and performs in situ burning of oil
- Safe flight operations with two small UAS operating in close vicinity with data streaming back.
- Both small UAS flew under Part 107 and so VLOS are maintained.
- Small UAS #2 takeoffs and land on a boat in Valdez Bay and return to continue missions.

### *5.6.5 CONOPS Summary – Pandemic lUAS*

Medical and Critical Supply Delivery: Major Hub to Rural Community [Fairbanks to Nenana and back]

#### 5.6.5.1 Pandemic lUAS Mission Purpose/Objectives

Purpose: Pandemic event, Rural community low on critical supplies, no road access, Airborne only possible. Crewed systems unable to fly due to IFR conditions. River is unsafe to use due to thin ice and ice blocks.

Goals: Take-off from Fairbanks, Safe operations in National Airspace System. Detect and Avoid capability with BVLOS mission. Land at Nenana [different from the original flight crew, second crew managing landing and switch during mission]. Extra ground crew at Nenana remove supplies and support UAS to return to Fairbanks.

Objectives: Large UAS operations with real-time data of flight route. Supplies received at Nenana. UAS return take-off occurs. Mission tracked at both GCS, Fairbanks and Nenana.

#### 5.6.5.2 Pandemic lUAS Mission Procedures/Approach

Large UAS: Operations from Fairbanks → Nenana → Fairbanks

Time of day - Early morning to represent overnight request for supplies

Type of operations - BVLOS with COA or waiver

Operations on ground at Fairbanks

- Original Flight Team will be based at Fairbanks overnight
- Pre-Flight checklist
- Take-off from Fairbanks

Flight from Fairbanks to Nenana - Switch flight ops to Nenana at halfway

- Watching landing at Nenana via own GCS and BVLOS
- Follow unloading and take-off from Nenana back to Fairbanks
- Flight from Nenana to Fairbanks - Switch flight ops to Fairbanks at halfway
- Manage landing back at Fairbanks

Operations on ground at Nenana

- Ground team based as Nenana overnight
- Setup to track flight in parallel to flight time
- Own Pre-Flight Checklist
- Track take-off at Fairbanks

Flight from Fairbanks to Nenana - Switch flight ops to Nenana at halfway

- Lead landing at Nenana, meet aircraft and unload
- Prepare flight for take-off back to Fairbanks
- Lead take-off at Nenana
- Flight from Nenana to Fairbanks - Switch flight ops to Fairbanks at halfway
- Follow landing back at Fairbanks via their own GCS and BVLOS

#### 5.6.5.3 Pandemic lUAS Mission Results

Observations: Real-time optical data from UAS along route, tracking of UAS at take-off location GCS as well as landing GCS. Recording supplies being unloaded and aircraft return take-off back to original location

Products: Optical data from on-board system. Detect and Avoid (DAA) tracking from GCS. Supplies received at Nenana. Record of all flight logs showing aircraft take-off from Fairbanks, landed at Nenana and then returned to Fairbanks with take-off from Nenana [note that original flight crew will stay at Fairbanks and flight crew + extra ground crew for supply removal at Nenana]

#### 5.6.5.4 Pandemic lUAS Mission Milestones

Outcomes/Actionable Intelligence

- Large UAS operations move critical cargo to a rural community
- Switching UAS tracking between two GCS
- Application of communication tools and practices for large UAS operations in NAS
- Transfer of cargo and critical supplies by  rural community team
- Return of large UAS to main hub to prepare for future supply delivery mission

Metrics of success

- Large UAS successfully takes off from Fairbanks with payload onboard
- Team at Nenana take over control of large UAS; still tracked by team at Fairbanks
- Team at Nenana land aircraft, team at Fairbanks tracks it
- Team at Nenana unload critical supplies and take-off again to go back to Fairbanks
- Team at Fairbanks sees supplies given to those in need at Nenana
- Team at Fairbanks take over control of large UAS; still tracked by team at Nenana
- Team at Fairbanks land aircraft, team at Nenana track it
- Safe landing at Nenana with BVLOS operations
- Supplies received by team that need it at Nenana
- Team at Fairbanks and Nenana able to simultaneously track aircraft throughout
- Safe return of large UAS to Fairbanks so that it could be reused for follow-on mission

### *5.6.6 CONOPS Summary – Pandemic sUAS*

Medical and Critical Supply Delivery: Two Rural Communities [Allakaket to Alatna].

#### 5.6.6.1 Pandemic sUAS Mission Purpose/Objectives

Purpose: Pandemic event, Rural community low on critical supplies, no road access, Airborne only possible. Crewed systems unable to fly due to instrument flight rules (IFR) conditions. Do not want people moving between communities. River between them cannot be used.

Goals: Take-off from Allakaket, Safe operations in the NAS. VLOS or EVLOS mission. Land at Alatna [different from the original flight crew, second crew managing landing and switch during mission]. Extra ground crew at Alatna remove supplies and support UAS to return to Allakaket.

Objectives: Large UAS operations with real-time data of flight route. Supplies received at Location #2. UAS return take-off occurs. Mission tracked at both GCS, Allakaket and Alatna.

#### 5.6.6.2 Pandemic sUAS Mission Procedures/Approach

Small UAS: Operations from Allakaket → Alatna →Allakaket

- Time of day - Early morning to represent overnight request for supplies
- Type of operations - visual line of sight (VLOS) or EVLOS with Part 107 Waiver

  Operations on ground at Allakaket

- Original Flight Team will be based at Allakaket overnight
- Pre-Flight checklist
- Take-off from Allakaket
- Flight from Allakaket to Alatna - Switch flight ops to Alatna at halfway
- Watching landing at location Alatna via own GCS and BVLOS
- Follow unloading and take-off from Alatna back to Allakaket
- Flight from Alatna to Allakaket - Switch flight ops to Allakaket at halfway
- Manage landing back at Allakaket

Operations on ground at Alatna

- Ground team based as Alatna overnight
- Setup to track flight in parallel to flight time
- Own Pre-Flight Checklist
- Track take-off at Allakaket
- Flight from Allakaket to Alatna - Switch flight ops to Alatna at halfway
- Lead landing at location Alatna, meet aircraft and unload
- Prepare flight for take-off back to Allakaket
- Lead take-off at Alatna
- Flight from Alatna to Allakaket - Switch flight ops to Allakaket at halfway
- Follow landing back at Allakaket via their own GCS and BVLOS

#### 5.6.6.3 Pandemic sUAS Mission Results

Observations: Real-time optical data from UAS along route, tracking of UAS at take-off location GCS as well as landing GCS. Recording supplies being unloaded and aircraft return take-off back to original location

Products: Electro-optical data from on-board system. Detect and avoid (DAA) tracking from GCS. Supplies received at Alatna. Record of all flight logs showing aircraft take-off from Allakaket, Landed at Alatna, and then returned to Allakaket with take-off from Alatna [note that original flight crew will stay at Allakaket and flight crew + extra ground crew for supply removal at Alatna]

#### 5.6.6.4 Pandemic sUAS Mission Milestones

Outcomes/Actionable Intelligence

- Small UAS operations move critical cargo from Allakaket to Alatna and back
- Switching UAS tracking between two GCS
- Application of communication tools and practices for small UAS operations in NAS
- Transfer of cargo and critical supplies by Alatna team
- Return of small UAS to main hub to prepare for future supply delivery mission

Metrics of success

- Small UAS successfully takes off from Allakaket with payload onboard
- Team at Alatna take over control of small UAS; still tracked by team at Allakaket
- Team at Alatna land aircraft, team at Allakaket tracks it
- Team at Alatna unload critical supplies and take-off again to go back to Allakaket
- Team at Allakaket sees supplies given to those in need at Alatna
- Team at Allakaket take over control of small UAS; still tracked by team at Alatna
- Team at Allakaket land aircraft, team at Alatna track it
- Safe landing at Alatna with VLOS/EVLOS operations
- Team at Allakaket and Alatna able to simultaneously track aircraft throughout
- Safe return of small UAS to Allakaket so that it could be reused for follow-on mission

### *5.6.7 CONOPS Summary – Train Derailment*

Train Derailment in Burlington, Vermont and impacted local infrastructure

#### 5.6.7.1 Train Derailment Mission Purpose/Objectives

Purpose: A train derails as it approaches the Burlington, Vermont Amtrak station and then hits the local infrastructure. Need to perform search and rescue on the derailed carriages and assess safety of the railroad infrastructure.

Goals: Large UAS keeps continued eyes on the area and crash site to get data to operations center. Local small UAS Part 107 pilots respond and provide data. Mobile small UAS responds to needs of operations center and get data on the event and support ground operators. Ground teams can used small UAS #1 data to target search. Small UAS #2 support team to rapidly assess if fuel leak and need to mitigate. Small UAS #3 collect data to rapidly assess safety of local infrastructure and target mitigation for further disaster. Communications between the multiple UAS flight teams. Operations Center communicates with pilots in command and get small UAS to move field of view based on observations seen. Get mobile small UAS to move to area of impact.

Objectives: Large UAS with real-time data to GCS and onto operations center used to provide airborne surveillance from above the derailment event and view the full extent of the disaster. Small UAS #1 gets visible (electro-optical) and thermal eyes on the derailed train and data can be used by ground teams to target their search for survivors. Data collected of sufficient accuracy to reconstruct the crash site to virtually assess the event after the missions. Small UAS #2 is flown to provide multispectral data around the crash site so that the ground teams can determine if fuel leaked from the train. Can be the second UAS for search and rescue. As with small UAS #1, data collected of sufficient accuracy to reconstruct the crash site to virtually assess the event after the missions. Small UAS #3 is the response UAS to damaged infrastructure, like buildings and bridges. Data collected of sufficient accuracy to reconstruct the crash site to virtually assess the event after the missions. Real-time data sent back to support assessment of infrastructure to send response teams and if further disaster could be averted. Evaluate how small UAS missions can respond to large UAS operations and data analysis. Evaluate how Part 107 pilots can respond to needs of State and/or City agencies. Evaluate how ground teams will react to data from small UAS and optimize search for survivors, mitigate fuel leaks, and ensure damaged infrastructure is safe. Collected data and images can be used to build models of the crash environment to support future analysis post missions.

#### 5.6.7.2 Train Derailment Mission Procedures/Approach

Large UAS: Rapid response take-off from Burlington airport

- BVLOS operations
- Flown from nearby runway to then have holding pattern above Burlington Station
- Multiple hours of flying to provide high altitude eyes on disaster
- VFR/IFR conditions as will be BVLOS - able to fly in full range of conditions

Small UAS #1: Search and Rescue small UAS flown around train crash

- Part 107 waiver and SGI waiver; Visual line of sight (VLOS) operations
- Eyes on train from electro-optical/thermal; Data to ground teams to help assess focus areas
- Can adapt flight to needs of ground teams

Small UAS #2: Manual small UAS operations: Supports assessment of any fuel leak from train crash

- Pattern defined by operations team to track any leak and map the surrounding area
- VLOS with Part 107 or SGI waiver
- VFR conditions [IFR if event limits visual observer from keeping VLOS]

Small UAS #3: Manual small UAS operations response to damaged infrastructure, such as buildings and/or bridges

- Ability to respond to any location requested by operations team
- Aim to stay as VLOS but may need extended-VLOS (EVLOS) or BVLOS

#### 5.6.7.3 Train Derailment Mission Results

Observations: Recording of full extent of the event from a large UAS whose flight pattern aims to provide continued data collection. At least three small UAS used. Small UAS #1 is to support ground teams for search and rescue with electro-optical and thermal sensors. Real-time data streamed back and captures images and video for reconstruction of scenes after missions. Small UAS #2 is a mobile system with electro-optical/thermal/multispectral [Visible, Red-edge, and near-infrared combined] payload and flown at low altitude around the crash site to support assessment of any fuel leaks on the local landscape. As with small UAS #1 real-time feeds and raw images collected to support post flight product generation. Small UAS #3 provides UAS capabilities to map damaged infrastructure like buildings and bridges. Real-time feeds back and images/videos collected to support the team to reconstruct the scenes to build virtual models for damage assessment.

Real-time Mission Products: Large UAS: Electro-optical/thermal video feeds back to operations center. Small UAS #1: Electro-optical/thermal videos back to operations and those on the ground for search and rescue. Small UAS #2: Multispectral [electro-optical with visible+Red-edge+near-infrared] videos back to operations center to assess if fuel leaks. Small UAS #3: Electro-optical feeds back to allow real-time assessment of infrastructure. Data from all UAS displayed in geospatial interface to superimpose on other available data from state, federal, and local agencies.

Post-Mission [fast response] Products: Three-dimensional models of the data from small UAS #1 and #3 to support virtual inspection of the train crash and any damaged infrastructure. This allows those in operations to analyze the events without having to be placed in the middle of the SAR response and damage mitigation of the infrastructure.

#### 5.6.7.4 Train Derailment Mission Milestones

Outcomes/Actionable Intelligence

- Large UAS able to fly under TFR or waiver to provide above disaster operations
- Electro-optical data feed from large UAS back to GCS ⇒ Feed into local operations center to support small UAS mission
- Small UAS #1 provides thermal and electro-optical imagery to those on the ground
- Small UAS #1 data back to GCS ⇒ Displayed for operations center + for those ground operations
- Small UAS #2 provides real-time feed of electro-optical data of landscape around train carriages
- Small UAS #2 multispectral data downloaded after mission ⇒ uploaded to visualization tool for operations center
- Small UAS #3 provides electro-optical video feed of impacted infrastructure to operations center
- Small UAS #3 post-processed data provided three-dimensional model of bridge

Metrics of success

- Large UAS streams data back to the incident center to support assessment of full extent.
- Small UAS #1 streams back data to operations center and can move field of view based on needs.
- Small UAS #1 data helps SAR teams to find survivors and optimize their search patterns.
- Small UAS #2 finds a fuel leak and can map its spread; or can provide a second SAR team.
- Small UAS #3 responds to damaged infrastructure and allows the ground team to determine where to send personnel to ensure the safety of the building/bridge.
- Safe flight operations with three small UAS and one large UAS operating and data streaming back.
- All small UAS flew under Part 107 and VLOS to EVLOS is maintained.

- Geotagged images and video collected to reconstruct the event in a virtual environment for post-mission assessment of the event.

### *5.6.8 CONOPS Summary – Volcano*

Mission involves Volcanic Plume and Downwind Cloud Hazard Assessment.

#### 5.6.8.1 Volcano Mission Purpose/Objectives

Purpose is to determine the current situation regarding a volcanic eruption with plume and clouds putting population/infrastructure at risk.

Goals: Sample the ash/gas concentrations to assess hazard levels, Thermal and electro-optical mapping of summit to support observatory and ground observations

Objectives: Large UAS operations with real-time data or post-processed samples. Small UAS operations at summit to sample plume and map active regions. Small UAS downwind missions to measure ash and gas concentrations

#### 5.6.8.2 Volcano Mission Procedures/Approach

Large UAS: BVLOS High altitude observations

- Early morning take-off, Flown from runway into TFR at summit
- Day of flying to reach summit
- VFR/IFR conditions as will be BVLOS and traveled from runway to volcano
- Sample plume through predefined routes and re-sample based on data

Small UAS #1: Summit mapping, if possible

- VLOS operations with Part 107 waiver and special governmental interest (SGI) waiver
- Flown in the TFR region - match when large UAS overhead and small UAS downwind
- VFR conditions
- Sample the plume and map the summit in electro-optical and thermal

Small UAS #2: West Anchorage: between volcano and Anchorage airport

- Downwind operations in community; Site chosen based on predicted cloud locations
- Time of flights to match small UAS #1 missions and/or other observations
- VLOS with Part 107 waiver if needed based on time of day/location/altitude
- VFR conditions
- Vertical profile of ash/gas concentrations

#### 5.6.8.3 Volcano Mission Results

Observations: Ash/gas concentrations are measured to understand risk to airports, aviation travelling in and out of the region. Data to be collected for volcano observatory and U.S. National Weather Service for forecasting. Optical and thermal imaging of the summit region to build three-dimensional (3D) models and orthomosaics.

Products: Orthomosaics in optical and thermal wavelengths of summit as well as 3D models where SfM is possible given plume opacity. Ash and gas concentrations along specific routes and manual sampling. 3D profiles through the plume and downwind clouds. Vertical profiles at point locations with VTOL small UAS.

#### 5.6.8.4 Volcano Mission Milestones

Outcomes/Actionable Intelligence

- Large UAS able to fly in National Airspace System and into and out of TFR
- Large UAS electro-optical data feed goes back to operations center and/or volcano observatory
- Small UAS #1 able to reach active region
- Small UAS #1 able to send back electro-optical data, produce surface model and thermal map of the summit
- Small UAS #2 able to respond to need for downwind vertical profile, gain permission
- Small UAS #2 able to sample cloud and get data back to volcano observatory and NWS
- All UAS data pushed to online website for operations enter and volcano observatory to examine/display

Metrics of success

- Large UAS streams data back to the incident center to support assessment of full extent.
- Small UAS #1 streams back data to support those on ground to mitigate hazards.
- Small UAS #2 samples downwind clouds; data for all involved in operational response
- Small UAS #2 pilot in command responds to commands from the incident center on where observations are needed.
- Safe flight operations with two small UAS operating in close vicinity with data streaming back.
- Both small UAS flew under Part 107 waivers and so VLOS is maintained.
- Small UAS #2 takeoffs and land in the local community and collects vertical profile
- SGI/Part 107 waiver given for small UAS #2 to support > 400 ft vertical profiles

### *5.6.9 CONOPS Summary – Wildland Fire #1*

CONOP involves collection of thermal and electro-optical imagery and video of the prescribed burn as well as the application of a fire suppression payload.

#### 5.6.9.1 Wildland Fire #1 Mission Purpose/Objectives

Purpose: Prescribed burn at Tanacross, Alaska with ignition of fuels and suppression of fire

Goals: Get multiple small UAS operating in the same area, each taking on different roles. Demonstrate that small UAS can provide ignition and retardant material and also map the fire spread to minimize risk for crewed aircraft and ground crews.

Objectives: Small UAS #1 is a fixed location to support teams to get real-time analysis of missions as they are ongoing and to support teams to evaluate effectiveness of missions and the implementation of the operations. Small UAS #2 provides pre, during, and post fire observations at lower altitude [Pre: electro-optical-near-infrared[NIR]/thermal infrared[TIR]/LiDAR; During: RGB/TIR; Post: RGB-NIR/TIR/LiDAR]. Small UAS #4A - #4D provides the same altitude eyes on the missions. Small UAS #3A is able to ignite the prescribed burn in a location that is difficult to access for ground teams. Small UAS #3B can access the fire edge and release retardant to stop fire spread. Evaluate how small UAS missions can respond to other small UAS operations and data analysis. Evaluate how 107 pilots can respond to needs of a community and how Part 107 operations can provide full aspects of prescribed burn needs.

#### 5.6.9.2 Wildland Fire #1 Mission Procedures/Approach

sUAS#1:

- Fixed tethered view of all of the missions
- EO and TIR data shared through tethered system
- Field of View allows full view of all operations [take-off, flight, and landings]; Fly VLOS or EVLOS under VFR conditions; Will stay airborne until operations complete

sUAS #2A: 1st flight; VLOS operations

- EO/VNIR/TIR camera with LiDAR; Provide real-time data and build mosaiced maps and 3D models
- Post flight: LiDAR point clouds to assess local vegetation and canopy near to burn areas
- Flown from launch site for use by all sUAS; Route defined to cover the area that will be burned; VFR conditions as will be VLOS

sUAS - #3A and #4A [#3A - Carry fire ignition material; #4A - EO and TIR payload for eyes on the event]

- Part 107 operations, flight #3A at higher altitude to view the full burn area
- Fly VLOS or EVLOS under VFR conditions

sUAS - #2B and #4B [#2B - EO, VNIR, and TIR payload to map the fire; #4B - EO and TIR payload for eyes on the event]

- Part 107 operations, flight #4B to view the full burn area
- Flight #2B has defined pattern and also can move based on data from #3B

sUAS - #3B and #4C [#3B - Carry fire retardant material; #4C - EO and TIR payload for eyes on the event]

- Part 107 operations, flight #4C to view the full burn area
- Flight #3B will move to area needed for retardant based on data from #4B

sUAS - #2C and #4D [#2C - EO/VNIR/TIR camera with LiDAR; #4D - EO and TIR payload for eyes on the event]

- #2C - Provide real-time data and build mosaiced maps and 3D models; Post flight: LiDAR point clouds to assess impact to vegetation and any canopy
- #4D will watch how #2C maps the edge of fire and collects LiDAR data
- #2C follows pattern based on data from flight #4C

#### 5.6.9.3 Wildland Fire #1 Mission Results

Observations: Recording of full extent of fire spread. Data feeds back to operations center. Small UAS #4 is a fixed and tethered system to provide red-green-blue electro-optical and thermal data to support post-mission evaluation of effectiveness of all flights, ground team effectiveness and operational timing. Small UAS #2 is mapping the land before burn [with LiDAR to map any canopy/vegetation], the progression of the fire, and extent of the burned areas. Small UAS #3 will release the ignition material and the retardant to stop the fire. Small UAS #4 fly at same altitude as missions to watch the other flights and support the ops center to monitor the flights and connect to the pilots in command (PIC’s) of small UAS #2 and #3.

Real-time Mission Products:

- Small UAS #1 - electro-optical visible data feeds through tether along with archived data for post mission evaluation.
- Visible and thermal data feedback to GCS and operations center from all.
- Small UAS #4A - #4D to provide eyes on the missions.
- Data displayed in geospatial interface to superimpose on other available data from state, federal, and local agencies.
- Small UAS #2A - #2C provide electro-optical visible, near-infrared (NIR), and thermal data real-time video feeds that can be assessed in operations center.
- Note that small UAS #2A and #2 for pre and post fire have sensors to map vegetation and landscape to determine pre landscape including any canopy and post impact on vegetation.
- Small UAS #3A and #3B data shows release of ignition and retardant materials into the correct locations.

Post-Mission [fast response] Products:

- Small UAS#1: Full motion video of the missions with geo- and time-tagged data to compare to data from other small UAS and flight software.
- Small UAS #2A - #2C: visible, NIR, and thermal videos of pre, during and post fire landscape [LiDAR point clouds for small UAS #2A and #2C].
- Mosaiced maps with derived properties of landscape along with surface models where structure from motion (SfM) is possible.
- Small UAS #3A and #3B: Videos in visible wavelengths of release of ignition and retardant with locations of released material.
- Small UAS #4A - #4D: Full motion video footage of the operations from the same altitude that superimposes with the post processed data from small UAS #2A- #2C.

#### 5.6.9.4 Wildland Fire #1Mission Milestones

Outcomes/Actionable Intelligence:

- Small UAS #1 - Tethered watching from the side with an off-nadir ability to monitor events. Electro-optical visible and thermal video feed of the events support local operations. Data feeds through tether along with power to provide sustained operations. Location such that it can watch all operations and be used to evaluate effectiveness of missions.
- Small UAS #2A, #2B, and #2C [Support at least three missions] [Mapping landscape before [#2A], during [#2B] and post fire, #2C] - Imagery captured prior to ignition to evaluate the landscape. Sent up once the fire started to have eyes on the event and capture images to build a mosaic of the landscape. Visible video feed back to pilot in command (PIC) and sent back into the local operations team. Three-dimensional rendering of the landscape available soon after the mission flew. FOV of visible camera seen by operations team so they can adapt flight as their needs. Small UAS #2C flown after #3A mission to evaluate if the area needed to be burnt has been completed and that the retardant has been successful.
- Small UAS #3A [ignition of land] - Ignite the area for the prescribed burn so the team does not need to send personnel on the ground.

- Small UAS #3B [Retardant] - Same  sUAS carries retardant onto the burned area to stop the fire. Small UAS #2C is mapping to assess the effectiveness of the retardant.
- Small UAS #4A - #4D [Monitoring of small UAS #2A and #2B] - Visible video of the events that supports the local operations team to assess effectiveness of the missions. Data back to operations team so that they can communicate with PIC of small UAS #3A, #2B, #3B, and #2C.

Metrics of success:

- Small UAS #1: Stays airborne throughout, visible and thermal data feed to ground control station, tether support data being streamed back as well as power to prevent need for new batteries
- Small UAS #4A - #4D: Stream data back to support assessment of prescribed fire missions and allow other PIC's to change flights in response to fire spread.
- Small UAS #2A produces mosaicked maps in visible, near-infrared, and thermal of the pre-fire landscape.
- Small UAS #2A produce point cloud observations to assess before #2B takes offs
- Small UAS #2C produce point cloud to determine if prescribed burn safe to leave
- Small UAS #3A drops of ignition cargo to start the prescribed burn at sites required.
- Small UAS #2B streams back data to support those on ground to assess fire extent.
- Small UAS #3B navigates to fire edge to suppress fire given data from small UAS #4C above.
- Small UAS #2B responds to commands from the incident center to fire edge from small UAS #4C data.
- Small UAS #3C maps the edge of the fire and data shows that fire has been suppressed and safe to end operations.

### *5.6.10 CONOPS Summary – Wildland Fire #7*

A new wildland fire is detected in satellite data. lUAS operations are initiated to map landscape and determine where to send sUAS #1 and #2. sUAS #1 operations to map new hotspots seen from satellite. sUAS #2 operations to detect smoke from the new wildland fire. sUAS #3 operations ahead of fire spread to measure VNIR NDVI of fire fuels to support the fire modeling community.

Site 1: Oregon [Example: Klondike and Taylor Creek from 2018]

Site 2: New Mexico [Example: Pose Fire, El Rito, NM - from 2021]

Site 3: Alaska [Example: Funny River from 2014]

#### 5.6.10.1 Wildland Fire #7 Mission Purpose/Objectives

Purpose: Wildland fire is seen in satellite data and/or reported from ground teams, need large UAS high altitude operations above, small UAS to keep eyes on all missions and backup communications, small UAS to determine size and intensity, small UAS provide downwind smoke plume and dispersing cloud measurements to support prediction of air quality and other gasses, downwind fire fuels from sUAS to support fire prediction spread modeling.

Goals: Large UAS mapping above the area where fire is seen in satellite data. Small UAS #1 - visible and thermal data to map the fire edge with location defined by detection from satellite feed or other report on fire location. Small UAS #2 - plume [connected to fire] and dispersing cloud sampling downwind of the small UAS #1 operations [also atmospheric data to determine mixing height/determine stability of the atmosphere]. Small UAS #3 - ahead of the fire spread to produce visible-near-infrared (NIR) and thermal infrared (TIR) data to obtain vegetation index information and data to derive fire weather indices at higher resolution from satellite and models. Also, if possible, have LiDAR to map local vegetation and provide data on any canopy to help fire spread modeling determine if surface fire could jump to canopy fire. Get multiple small UAS in the air to provide essential data to better understand the fire size and fill data gaps to support the team to predict the air quality/cloud dispersal and fire spread. Show how small UAS can together provide an improved understanding of a fire and provide the data that modeling groups need to better predict airborne and ground hazards.

Objectives: Large UAS provides a higher altitude view of the event and support teams to determine positions for the small UAS. Small UAS #1 is a tethered system at a fixed location to support teams to get real-time analysis of missions as they are ongoing and to support teams to evaluate effectiveness of missions and the implementation of the operational missions. Small UAS #2 provides thermal and visible-NIR data to map out the fire perimeter and provide broadband thermal infrared data to derived ground temperatures. Small UAS #3 provide aerosol and gas observations to map the plume and downwind cloud as well as atmospheric measurements to support air quality assessment team to derive atmospheric stability and mixing ratio. Small UAS #4 provides visible-NIR, TIR, and LiDAR data to map the downwind fire fuels to support the fire spread modeling team and fill data gaps. Evaluate how small UAS missions can respond to other small UAS operations and data analysis. Evaluate how 107 pilots can respond to operational needs where the launch site depends on fire location and downwind direction and how a suite of Part 107 operations can provide full aspects of wildland fire current size and likelihood to spread.

#### 5.6.10.2 Wildland Fire #7 Mission Procedures/Approach

Large UAS: Eyes above and support sUAS position

- Take-off from nearby airport once report of fire. Site 1 in Oregon - Eugene if responding to Klondike/Taylor Creek ‘18 fire; Site 2 in Alaska - Anchorage if responding to Funny River ‘14 fire; Site 3 in New Mexico - Santa Fe if responding to El Rito ‘21 fire
- Beyond line of sight (BVLOS) operations; Flown from runway to traverse to fire location
- Route defined to reach site efficiently and then holding pattern to keep eyes on fire
- Day of flying to reach site and provide high altitude eyes on disaster
- Small UAS #1: Tethered to watch other small UAS and communication link if needed
- Stays airborne to watch all following missions; Take-off location dependent on fire location and any updates from large UAS data

Part 107 and visual line of sight (VLOS) operations; Fly VLOS or extended-VLOS under visual flight rules (VFR) conditions

- This will act as fixed tethered view of all of the missions
- Electro-optical visible and thermal data shared through tethered system; Sensor field of view allows full view of all operations [take-off, flight, and landings]

Small UAS #2: Mapping of the fire to determine intensity and perimeter

- Take-off location selected to support analysis of the fire size

Part 107 and VLOS operations; Electro-optical visible, NIR, and TIR camera suite

- Provide real-time data and build mosaiced maps and three-dimensional models
- Route defined to cover the fire and map is thermal signal and edge

Small UAS #3: Plume/Cloud details and atmospheric conditions

- Take-off location selected based on location of the fire and plume; Mission design to measure plume top height and then direction and dimensions of cloud

Part 107 may require EVLOS operations; Maybe instrument flight rules (IFR) conditions if the plume/cloud optically thicken

- Aerosol sampler, gasses sensor, with include relative humidity (RH), temperature (T), and Pressure
- Real-time data to provide where plume top is detected; Sample the plume and follow dispersing cloud, manual flight based on the data at ground control station

Small UAS #4: Fire fuels and landscape details ahead of fire spread and upwind of plume/cloud

- Take-off location selected based on fire location and need for data where fire will spread
- Gridded data collected to map the landscape ahead of the fire
- Part 107 but might require EVLOS given distance to cover based on pilot in command location
- Electro-optical visible, NIR, and TIR camera suite along with LiDAR, if possible, to measure height of vegetation and any canopy
- Real-time electro-optical visible data streamed back so that manual flight can be selected if needed
- Fire spread modeling team member with PIC to assess the areas that needs mapping
- Maybe IFR conditions if the plume/cloud is optically thick over the area to be mapped

#### 5.6.10.3 Wildland Fire #7 Mission Results

Observations: Recording of full extent of the fire as it progresses. lUAS data feeds back to EM Ops Center and to support sUAS teams to produce fine-scale data needed by ground team, AQ modelers and fire spread modeling team. sUAS #1 to support eyes on the event and communications hub if needed. sUAS #2 to map fire perimeter and intensity, sUAS #3 to measure plume height plus composition as well as atmospheric conditions, sUAS #4 to map fire fuels ahead of the fire spread and fill data gaps needed by the modeling team.

Real-time mission Products: lUAS provides RGB and TIR feeds to support ground teams on where to place sUAS. sUAS #1 is flown from set-location, that can move to location as defined needs arise, to support teams to get real-time analysis of missions as they are ongoing and to support teams to evaluate effectiveness of missions and the implementation of the CONOPS. sUAS #2 provides RGB-NIR/TIR data in real-time and observations to determine fire perimeter and intensity. sUAS #3 provides vertical profiles of plume/cloud top height and RH, T, and P to derive plume/cloud composition along with atmosphere stability and mixing height. sUAS #4 provides real-time feed of RGB-NIR and TIR data.

Post-Mission [fast response] Products:

- lUAS: Geospatial located video feeds to show field of view to analyze full extent of fire.
- sUAS#1: Full FOV of the missions with geo- and time-tagged data to compare to data from other sUAS and flight software.
- sUAS #2: Derived ground surface temperature of fire and perimeter. Mosaiced maps with derived properties of landscape along with DEM/DSM/3D models where SfM is possible.
- sUAS #3: Plume/cloud composition along sUAS route including vertical and horizontal profiles. Atmospheric data used to derive atmospheric stability and allow the AQ modeling team to measure mixing ratio.
- sUAS #4: LiDAR 3D point clouds of the upwind landscape and infrastructure ahead of the fire and where it is predicted to spread.
- Mosaiced maps with derived properties of landscape along with DEM/DSM/3D models where SfM is possible.
- Superimposed TIR and NIR/NDVI data on 3D models from RGB and LiDAR data.

**5.6.10.4 Wildland Fire #7 Mission Milestones**

Outcomes/Actionable Intelligence:

- Large UAS [Higher altitude eyes] - Adaptable mission to map the full extent of the new fire seen from satellite data. Electro-optical visible and thermal infrared video data feedback to GCS and piped into operations center to determine where to send small UAS teams. GCS team in communications with operations center and small UAS teams.
- Small UAS #1 [Eyes on missions and backup communications] - provides electro-optical visible and thermal data of all other small UAS missions to assess success to complete missions. Onboard communications can support radio connections between small UAS #2 - #4 and main operations center. These communications will act as mitigation measure to minimize risk that another communications network goes out
- Small UAS #2 [hotspots] - Based on satellite data with accompanying spot weather forecast request, and local wildland fire alert. Part 107 pilot under VLOS goes to locations close to detected fire and fly patterns to collect electro-optical visible and thermal data. Videos feed in real-time back to GCS and piped to decision makers. Imagery taken to build a mosaicked map of visible data with superimposed thermal map. Real-time feed used by event chief to determine need for group ops. Products: Spot Detection and Fire Perimeter map
- Small UAS #3 [plume/cloud content and atmospheric stability/mixing height] - Based on data from small UAS #1, these operations will fly downwind of the fire to measure any smoke particulates and gasses from the fire. Most likely will be flying EVLOS as it will need to fly beyond pilot location to map out the extent of the plume and cloud. It will give a sampler onboard to get data back to GCS and displayed in real-time into the visualization tool. Data off the small UAS available to plume model community and provided to U.S. National Weather Service (NWS) for reporting on airborne particulates and if any significant gas content. It will have onboard atmospheric sensors to provide data to support derivation of mixing height and atmospheric stability of the atmosphere.
- Small UAS #4 [ahead of fire fuels mapping] - This will be set up ahead of the fire locations seen in the satellite data and based on likely fire spread direction. Data will be collected to benefit the fire spread modeling, so will need this input first and define location for operations to provide data to fill a gap in their needs. It will be providing high resolution

visible, multispectral data [visible+Red-edge+near-infrared] with where possible LiDAR of the landscape for fire fuels to support fire spread models. Real-time: Video feeds of electro-optical visible data. Fast-turn around: Vegetation indices and fuel-data from individual images. Post-mission: Mosaicked maps of vegetation indices and other products such as point clouds to assess high resolution maps of vegetation and local canopy.

Metrics of success:

- Large UAS streams data back to the incident center to support assessment of full extent.
- Small UAS #1: Stays airborne, electro-optical visible and thermal infrared feeds back to GCS, tether continues to support data being streamed back and power to prevent need for new batteries.
- Small UAS #2 streams back data to support team to assess fire size and provides TIR data to derive fire intensity and map fire perimeter.
- Small UAS #3 provides aerosol data to determine constituents of cloud and plume as well as plume top height for air quality modeling team.
- Small UAS #3 collects atmospheric data to support derivation of atmosphere stability and mixing ratio.
- Small UAS #4 maps the area ahead of the fire and data used to derive three-dimensional models of the landscape with superimposed visible, NIR, and TIR data.
- Safe flight operations with multiple small UAS operating and data streaming back.
- Both small UAS flew under Part 107 and VLOS is maintained.

## 5.7 UAS Technology Evaluation

Disasters are frequently unpredictable with respect to timing, scale, impact, and subsequent events (Sagun et al. 2009). Confronting the immediate and enduring effects of disasters requires systematic organization of people, labor, and resources and increasingly a range of advanced technologies are used in disaster and emergency response situations (ITU, 2019). The rapid proliferation of digital infrastructure and devices including wireless broadband networks, cloud computing, and smartphones coupled with the development and adoption of technologies such as AI, the IoT, social media platforms, robotics, and Autonomous Flying Vehicles (AFVs) has enhanced data collection and communication throughout the world (ITU, 2019; Torres, 2018). Accordingly, the use of advanced technologies has greatly increased for civil purposes such as law enforcement, environmental monitoring, agricultural management, search and rescue operations, infrastructure assessment, etc. over the past decade. The team has provided a short overview of some commonly used advanced technologies in emergency management and disaster response situations and discuss a number of challenges associated with some of these technologies.

### *5.7.1 Artificial Intelligence (AI)*

AI refers to intelligence demonstrated by software or hardware/software combinations that possesses the ability to learn, reason, plan, and/or process natural language (Wikipedia, 2021). AI is particularly useful in processing information, assisting with, or analyzing emergency calls, analyzing social media, and in performing predictive analytics (ITU, 2019). Examples of AI use in emergency management include the Association of Public-Safety Officials (APCO) partnered with IBM Watson to use speech-to-text analytics software to help analyze 911 conversations to help train 911 call responders (Torres, 2018). The city of Memphis, TN used Watson Analytics to examine trends in emergency medical services, which helped reduce emergency service costs by $20M (Torres, 2018). Several large cities in California adopted the One Concern AI platform to provide analytical disaster assessment. The platform can model an entire city infrastructure system and predict disaster specific damages at the resolution of a city block with 85% accuracy within 15 minutes (Torres, 2018).

### *5.7.2 Internet of Things (IoT)*

The IoT refers to an integrated network of physical sensors and software that collect data and communicate in real-time (ITU, 2019; Torres, 2018). In disaster and emergency management, IoT is used to enhance data collection and quickly communicate these data to planning and emergency response agencies. Sensor equipped devices can collect and disseminate data related to temperature, water quality, or smoke from areas that may be difficult for emergency response teams to reach. In response to a 2010 landslide that killed more than 50 people in Rio de Janerio, Brazil, the City Hall Operations Centre (CHOC) was built in collaboration with IBM (ITU, 2019). CHOC continuously monitors weather sensors, the electricity grid, traffic controls and traffic signals, GPS-equipped public transit vehicles, and social media feeds uses text messaging, radio, and television to inform the public when an emergency situation arises (ITU, 2019).

### *5.7.3 Blockchain*

Blockchain is another technology that can be used in emergency management to promote interoperability and transparency regarding financial transactions and information exchanges during and after an emergency (ITU, 2019; Torres, 2018). In disaster situations, blockchain can allow multiple parties to coordinate resources. The Center for Disease Control (CDC) is in the process of piloting blockchain for the use case of public health surveillance data to collect and communicate data to the various groups that treat patients in disaster relief scenarios. Blockchain provides an enduring record of what resources are dedicated to a specific area and by whom, which is accessible to everyone.

#### *5.7.4 Robots (including UAVs)*

Robots integrated with microprocessors and sensors are ideal for emergencies that are too dangerous for humans or rescue animals (ITU, 2019). Search-and-rescue robots played an important part in rescue and recovery operations following the 2001 World Trade Center attack. Since then, more than 50 emergency related deployments of robots have been reported. Drones and uncrewed air or water vehicles are being increasingly used in disaster and emergency management situations (Finn and Donovan, 2016). The first documented use of UAVs was after Hurricane Katrina in 2005 to search for survivors and assess water levels (ITU, 2019). UAVs have been used in a wide range of disaster management scenarios throughout the world to deliver blood and medical supplies (Smyth, 2017).

When considering the use of technologies in the context of disaster management and response, a number of potential issues can arise. These issues largely center on questions related to the use and coordination of various technologies and data, as well as technical and legal issues regarding data collection, storage, and privacy.

First, a disaster of any type is associated with uncertainty, which increases as the magnitude/scale of the event increases. Disaster management teams want to respond quickly and use all available resources at their disposal – particularly when lives are at stake. Unfortunately, in the context of advanced technologies, it is not necessarily clear who (which people in which agencies) is responsible for the use of specific technologies or has access to and is currently using which technology(-ies). Thus, situations can arise where multiple agencies may respond with different technologies, or even employ the same technology, in an ad hoc manner. In these situations, confusion, and possibly even competition can arise and may be exacerbated when different stakeholders operating at different levels of governance (local, state, federal), volunteer organizations, and even civilian bystanders attempt to deploy and use different technologies in the response. This does not mean that there are no rules guiding disaster response, just that it is not necessarily clear how technologies are to be employed or exactly which of the available technologies should be employed at what time.

Specific challenges as noted by Minges (2019) can include, but are not limited to:

- **Standardization:** The use of incompatible or different technologies and data formats, lack of universally agreed upon protocols for sharing or prioritizing the use of technologies, and the lack of social media rules regarding the use of standardized hashtags presents a challenge.
- **Scalability:** While the potential benefits associated with increased use of technologies in disaster management have yet to be fully appreciated, implementation appears rather informal and ad hoc or is in a “pilot” testing phase. Therefore, there needs to be a focus on identifying and documenting the most relevant or promising technologies (or applications of specific technologies) and scaling.

- **Coordination and access to/use of technology:** To date, there is a lack of agreement on exactly what technologies are preferred by first responders, relief management teams, and the public. There may be compatibility issues as well as overlaps regarding the use of specific technologies, platforms, and applications. Some local and state agencies may not have the resources needed to adopt and effectively use advanced technologies or to store and analyze data outputs.
- **Proper use and training**: There are many different types of technologies that can be used in different ways. Different users and agencies may have limited exposure to and experience with various technologies and while some technologies require few specialized skills (i.e., Twitter), the adoption and effective deployment of more advanced technologies such as AFVs require skilled operators. For example, different users of AFVs have different levels of training, or may have no formal training at all. Likewise, the ability to collect, manage, and analyze different types of data requires analytics training. Many of the skill sets needed to support the use of advanced technologies are limited (Minges, 2019).
- **Repository of Shared examples:** There is a need for documented examples of how technologies are used in disaster management or mitigation as well as suggestions, experiences, pros/cons, etc. Training manuals and seminars are also needed.

Second, the use of technology such as sensors, closed-circuit television, smartphones, financial transactions, etc. is associated with a massive amount of data generation and the ability to use those data. While the potential for collecting and analyzing massive amounts of real-time data from different sources to aid in disaster response is intriguing, the reality of such an endeavor is quite daunting. Clearly, data are not useful unless they are collected, stored, and managed in a systematic manner, and then can be analyzed and used very quickly. This, however, creates another set of challenges related to data collection and management.

- **Ethics and Privacy issues:** While data privacy issues (who has access to potentially individualized data and how those data are used) have received quite a bit of attention in disaster response literature (Sanfilippo et al., 2020), there are broader ethical concerns associated with the use of technology in disaster response. For example, how should technologies be used to influence decisions on where to concentrate relief efforts, assess acceptable levels of risk to rescuers, whom to rescue first, whom to treat first, whom might be left behind or left to wait. These are all moral questions (Battistuzzi et al., 2021; Gustavsson, 2019). The urgency of an emergency often requires difficult decisions and the ability to prioritize. Thus, disaster responders are typically trained to manage morally challenging situations. It would be naïve to assume that such decisions are not affected by the use of technology.
- Although the use of different technologies and associated data in emergency management is becoming widespread, there are privacy and ethical concerns associated with the use of certain technologies, particularly location-based and video technologies that allow real-time location tracking and capture Personally Identifiable Information (PII) and Sensitive PII (Sanfilippo et al. 2020). While research has shown many people believe it is acceptable to share forms of PII in emergency scenarios (Apthorpe et al. 2018); disaster victims have expressed concerns that information collected during emergencies may be used

inappropriately or without their consent (SanFillippo et al. 2020). For example, in March 2019, FEMA inappropriately disclosed sensitive location and banking information from approximately 2.3 million victims of hurricanes Harvey, Irma, and Maria as well as the 2017 California wildfires to a contactor in direct violation of federal law and Department of Homeland Security policy (SanFillippo et al. 2020). Likewise, communication apps promoted as useful during disasters have raised concerns about persistent tracking where user concerns extend to both third-party apps as well as trusted organizations such as the Red Cross. Users note that some apps cannot be easily turned off and continue tracking unless they are uninstalled. Other users have been outraged upon finding out that tracking and user-based personalization continues even after these features have been disabled (SanFillippo et al. 2020). Similarly, many people have questions about the use of UAVs or drones and robots, which are increasingly being combined with advanced technologies such as sophisticated video capabilities, geographic information system sensors, RFID readers, and weather sensors (Finn and Donovan, 2016). While AFVs and other robotic technologies can offer unique perspectives and allow rescuers to gain access to difficult to reach or dangerous areas, public agency and emergency response operators, as well as private operators, can easily access any number of visual technologies and capture and stream video footage (Finn and Donovan, 2016).

- Disaster privacy is highly context dependent as it focuses on the perceived appropriateness of increased flow of personal information compared to “normal “or non-emergency situations (Sanfilippo et al. 2020). While emergency situations typically result in increased communication and associated information flows, the use of advanced technologies to aid in disaster response and communication both intensifies and complicates these flows and raises a number of important questions. How is an emergency or disaster defined? When does the event begin and when does it end? What information is appropriate to gather, who has access to it, under what conditions, and for how long? What happens to the information or data after the emergency ends? Are individuals aware that data are being collected about their locations and behaviors? (Sanfilippo et al. 2020). Asking and answering these types of questions are essential with respect to reconciling safety and privacy concerns.

It is important to recognize that concerns related to the collection and use of data extend beyond privacy and ethical issues.

- **Infrastructure:** Depending on where one is located and the corresponding characteristics and geography (urban versus rural, developed versus undeveloped, mountainous terrain, etc.) the underlying supporting communications infrastructure may or may not support the real-time use of certain technologies and data. For example, the communications infrastructure in New York City in the U.S. is quite different from a rural village in the mountains of Peru. Thus, the ability to collect and use data in a real-time manner is limited by the location of the event. Further, disasters – particularly large-scale disasters – can damage or destroy both communications and transportation infrastructure for substantial periods, making the use of data intensive technologies ineffective until the infrastructure is repaired.
- **Sheer volume of data:** During emergencies, call centers are often overwhelmed with voice calls, text messages, and social media images. Further, the volume of real time data

generated by technologies such as sensors, AFVs, and satellite-imaging can quickly overwhelm the storage capabilities of agencies.

"The overflow of information generated during disasters can be as paralyzing to humanitarian response as the lack of information. This flash flood of information is often referred to as Big Data, or Big Crisis Data. Making sense of Big Crisis Data is proving to be an impossible challenge for traditional humanitarian organizations…" (Meier, 2015).

- **Different types of data:** Different technologies collect and/or transmit different types of data using different formats. Not all agencies have access to specialized applications that are needed to process and use some types of data. Further, there are non-trivial challenges associated with combining (merging) data sets that are stored using different formats.
- **Accuracy or validity of data:** It can be very difficult to validate real-time data, particularly data generated via social media (Meier, 2015). Further, data of all types can be manipulated or censored by various actors in the name of security or for proprietary reasons. Although often equated with repressive countries, data manipulation happens everywhere. False information can be spread quickly in times of crisis, which, in turn, can affect disaster response. If inaccurate information is shared via an "official source", it becomes very difficult to reverse that message. Instead of empowering the most vulnerable, technologies can be used to reinforce and replicate existing power asymmetries (Sjodin, 2019).

"It is probably not unheard of for any of us that disinformation and false news are everywhere in our information age today. However, how much do we think of this phenomenon to have affected the crisis map we base our work on as practitioners in the humanitarian world? We have to keep in mind that when mapping a humanitarian emergency through data brought by social media and other technology, false or misleading information is hard to avoid. A crisis map can easily be sabotaged by people and agents deliberately adding false or misleading information, and it is very hard to identify subtle disinformation, as noted by Patrick Meier in *Digital Humanitarians*" (Sjodin, 2019).

- **Proprietary data:** Certain data are generated via platforms or applications that are considered proprietary and often have no formal sharing arrangements, only provide access to a limited amount of data, or only provide data for a fee. These data may be of little use to responders.

### *5.7.5 Blue UAS*

(Excerpted from "The Skies Grow Even More Blue for DoD UAS" by Dawn M.K. Zoldi, Col., USAF, Ret., Appearing in *Inside Unmanned Systems*, 8 October 2021):

Until 2017, when the U.S. Army first banned Chinese drones, their use was ubiquitous across the federal government. Based on similar cybersecurity concerns, the other military services and several federal agencies followed suit with their own policy prohibitions. Some precluded the use of federal grant funding by external entities to operate and/or purchase Chinese drones. Around the same time, additional parallel acquisition policies precluded the DOD from purchasing any Commercial Off-The-Shelf (COTS) drones.

In 2020, Section 848 of the Fiscal Year 2020 National Defense Authorization Act (FY20 NDAA) "Prohibition on Operation or Procurement of Foreign-Made Unmanned Aircraft Systems" codified the DOD ban into law. It prohibited the secretary of defense from operating or procuring UAS and any related services and equipment from China, including ones manufactured in or by an entity domiciled in that country. It also barred using flight controllers, radios, data transmission, devices, cameras, or gimbals manufactured in the PRC or by an entity domiciled in the PRC; a GCS or operating software developed in China or by an entity domiciled in China; and net- work connectivity or data storage located in or administered by an entity domiciled in China. It also prohibited the DOD from using a system manufactured in China or by an entity domiciled in China for the detection or identification of UAS and any related services and equipment.

On January 18, 2021, just days before departing the White House, former President Donald Trump signed Executive Order (EO) 13981—Protecting the United States from Certain Uncrewed Aircraft Systems—which prevented "the use of taxpayer dollars to procure UAS that present unacceptable risks and are manufactured by, or contain software or critical electronic components from, foreign adversaries, and to encourage the use of domestically produced UAS." The EO defined "adversary country" as inclusive of North Korea, Iran, and Russia, as well as China, and left the door open for the secretary of commerce to add more countries to the list. It required all federal agencies to account for such UAS within their fleets and cease using them. It directed the Office of Management and Budget to work with agency heads to find funding to replace them.

The Biden administration has thus far toed the line on Chinese drones. On September 8, 2021, according to a DOD news release, Deputy Secretary of Defense Kathleen Hicks signed into effect updated guidance (marked as "CUI," or controlled unclassified information) for the procurement and operation of its UAS. The release specifically called out Da Jiang Innovations (DJI) and stated that the policy allowed the department "…to take advantage of rapid techno- logical advancements of the commercial market while concurrently reaffirming the department's recognition that certain foreign-made commercial UAS pose a clear and present threat to U.S. national security. It enables the department to more freely use commercially developed UAS by better defining a process for clearing trusted systems and ensures the department's continued compliance with Section 848 of the National Defense Authorization Act for Fiscal Year 2020 and Executive Order 13981…"

In fall 2018, as the initial Chinese drone policy bans were falling into place, the Army was already engaged in selecting a single solution for a cybersecure, rucksack- packable UAS for its formal Program of Record (POR), Short Range Reconnaissance (SRR). It had already selected the five companies' UAS that we now know as Blue sUAS (FLIR ION M440, Parrot ANAFI- USA-Gov/mil, Skydio XD2, Teal Golden Eagle and Vantage Robotics) to provide specially prototyped/noncommercially available drones for this purpose.

In the midst of this process, Congress promulgated Section 848. The draft EO also started circulating around the Pentagon. The vendors had to adapt to ensure their drones were NDAA-compliant, as well as cybersafe.

As legal and executive policy bans became realities, DIU, the only DOD organization focused exclusively on fielding and scaling commercial technology across the U.S. military to help solve critical problems, engaged with the five companies already working with the Army's SRR POR to explore their interest in getting approved to be on the General Services Administration (GSA) Schedule as a cleared procurement option.

They all said yes. By September 2020, Blue was born.

And then came the Blue UAS Framework.

***Blue Pieces and Parts***

The Blue sUAS project was just the beginning of a larger effort for DIU. Next came the little-known Blue UAS Framework, which sought commercially available and legally compliant prototyped UAS components, such as data links, hardware, software, software sensors and gimbals.

When American and allied manufacturers went to the well to create NDAA- compliant UAS, the well was dry because adversary countries had cornered the market for some necessary materials and components. Capt. Shelby Ochs, USMC, co-program manager of Blue sUAS 2.0, explained: “We needed the Lego® bricks, the components, to make these drones available. So DIU put out the call. Industry answered.”

More than 60% of Blue sUAS incorporated compliant and interoperable “widgets” created under this Blue UAS framework from 2019 to 2020. ModalAI’s flight processor, VOXL, is one example of this tech, which is now also commercially available. Auterion’s Skynav hand controller and Skynode flight computer are others.

***The Next Iteration: Blue 2.0***

The Blue Framework and sUAS project have been successful. As one example, in support of the Afghanistan evacuation effort, at the request of security forces at Ramstein Air Force Base, Germany, Redwood City, California-based Skydio sent a solutions engineer and six systems for security and refugee protection operations. According to Ochs, “Just two days after the request came in, from flash to bang, Skydio deployed, trained and had our forces operational.”

Building on that success, DIU now focuses on Blue sUAS, version 2.0, at the request of the office of the under- secretary of defense for acquisition and sustainment—OUSD(A&S).

Unlike the original project, which leveraged specially prototyped UAS, this iteration involves COTS UAS, the policy of which OUSD(A&S) owns for the DOD. OUSD(A&S) sought to expand opportunities to bring a greater variety of UAS to the fight, including larger ones, with a wide range of modalities and capabilities and at different price points. A secondary part of the project involves an effort to define a common standard across the DOD for UAS vendor onboarding, the means to communicate that standard and a uniform process to assist vendors.

Using its 10 U.S. Code 2371(b) Other Transaction Authority (OTA), DIU pushed out a Commercial Solutions Opening (CSO) and Area of Interest (AOI) request in March 2021 on its website, sam.gov, on social media and to its distribution list, seeking industry proposals. In the 14 days it was listed, DIU received more than 100 responses.

From this group, DIU and its customers selected 11 companies, with 14 drones, for Blue sUAS 2.0 RPPs, including:

- Ascent AeroSystems
- BlueHalo
- Easy Aerial
- FlightWave Aerospace Systems
- Freefly
- Harris Aerial

- Inspired Flight
- senseFly
- Skydio
- Vision Aerial
- Wingtra

From July to September 2021, all vendors signed OTA agreements. From Sept. 14 to 16, several of these companies demonstrated their aircraft at the U.S. Air Force Academy in Colorado.

"We picked the Academy because it was the highest altitude we could find for our needs," noted Sean Anderson, a support contractor for the project and USAFA '09 grad. "Equally important, USAFA had established procedures for UAS flight that we could leverage on short notice."

From its perspective, USAFA was happy to assist DIU. Kevin Kenney, USAFA's small UAS project manager, explained: "We have six academic departments, significant dedicated research, as well as integrated remotely piloted aircraft operations here to inspire cadets to become leaders of character and RPA pilots. Hosting these demos was consistent with both DIU's needs and our mission." DIU provided cadets and faculty an opportunity to engage with demo vendors and see static drone displays in the academic building the day before flights occurred.

Michael O'Sullivan, head of global marketing and product management at senseFly, a Swiss-based company with 10 years of experience in making fixed-wing lightweight drones, talked about his excitement in having this opportunity to work with the U.S. military. "Partnering with DIU has been a collaborative and streamlined process to help list senseFly's commercial eBee TAC UAV in Blue sUAS 2.0 and provide a secure, trusted medium-range drone mapping solution and capabilities to the U.S. government." He continued: "The passion shown by DIU for using proven solutions is outstanding. Their way of working, entrepreneurial spirit, drive for excellence and guidance has made these demonstrations a real team effort."

Adam Bilmes, director of sales and cofounder at Inspired Flight, spoke about the value of the Blue sUAS 2.0 project. "This process has been a fantastic opportunity for Inspired Flight to further break into the defense ecosystem and generate a stamp of authority from the government spectrum." San Luis Obispo, California-based Inspired Flight is a UAV manufacturing startup with two drones—the IF1200 and the IF750—in the running for Blue sUAS 2.0. "The collaborative process that the DIU designed to shepherd our systems through Blue sUAS 2.0 also enabled us to maintain focus on growing our core commercial business around heavy lift, rugged and secure multirotors, accomplishing a wide range of mission sets."

The demos successfully proved the consistency and general flight performance of these dual-use drones on a military installation and in front of military and government sUAS reps across setup and prep, mission planning, launch and recovery, flight performance, safety of flight (e.g., autonomy, geofencing, obstacle avoidance). and validation of spec sheet accuracy.

***The Future Remains Bright… And Blue***

Next steps for these almost-Blue companies will involve navigating the DIU and OUSD(A&S) administrative approval processes. Once past those hurdles, they will officially become part of the DIU- cleared list of cybersecure and NDAA/ EO-compliant sUAS for government.

DIU projects that the approval timeline for this next tranche of Blue sUAS will allow them to be available to the DOD and IA partners that leverage this project no later than the end of the first quarter 2022.

Will there be a Blue sUAS 3.0? The answer will depend on agency demands and budgets. Meanwhile, the future looks bright—and blue—for DOD UAS.

#### 5.7.5.1 Blue UAS Requirements

Requirements (Criteria) Used in Previous Blue UAS Programs (Based on DIU Press Release of 15 Mar 2021) are as follows. Technical requirements are listed in Table 12.

1. Must comply with Section 848 of National Defense Authorization Act for Fiscal Year 2020 (See Appendix C)
2. Must comply with Executive Order 13981 of January 18, 2021 (See Appendix D)
3. Should aim to meet the following criteria:
    - Use cases include but are not limited to research and development, logistics, basic reconnaissance, or training.
    - Flexibility, versatility, and variety is encouraged; Size, Weight, and Payload (SWaP) trade-offs are expected, as well as variation in form factor and price.
    - Systems should be as secure as commercially feasible while demonstrating an ability to ensure data integrity.
    - Submissions are also expected to adhere to industry best practices for flight safety.
    - Systems will be selected based on the desire to present variations in size, weight, and power compared to overall cost (SWaP-C) to end users, while remaining below 55 pounds Maximum Take-Off Weight.
    - Variety in flight/launch modality and characteristics to fit a diverse range of users and missions.
    - Scalable computer hardware capable of flexibility/integration for a variety of payload configurations, continuous development, and upgrades.
    - Optimized payload to total weight ratio
    - Ability to meet a sustained production rate of greater than 10 units per 30 days
    - Ready-made instruction for basic FAA part 107 or similar DoD instruction qualified user

Table 12: DIU Blue UAS Technical Requirements

| DIU Blue UAS Technical Requirements | |
|---|---|
| **Requirement** | Threshold |
| **Weight** | < 55lbs |
| **Launch & Recovery** | VTOL |
| **Operational Range** | > 3 km |
| **Flight Endurance** | > 30 min. |

| | |
|---|---|
| **Environmental Hardness** | IP53 (Dust & Rain) |
| **Wind Tolerance** | > 15 mph winds |
| **Assembly Time** | < 2 min. |
| **Payload** | High Res., Day/Night, Stabilized, Swappable |
| **Architecture** | Open Source, QGC + MAVLink |
| **Cybersecurity** | US-Built SW & Critical Electronics |
| **Communications** | Military Bands, 1600-2500MHz & ISM Bands |
| ***Aside from the < 55lbs and MAVLink requirements, these characteristics are not absolute thresholds. They are approximate target performances that, within reason, should be included in capability and cost trade-offs.** | |

Note: Investigations into advanced technologies led to an investigation into the Blue UAS process. Surveys indicated that first responders want to utilize the technology and are not as much concerned about a Blue UAS process. As industry, driven by the Federal Government and DOD, continues to incorporate Blue UAS, more will be available to first responders. Research to date doesn't indicate a separate or even supported attempt to require these at the local, state level or in the civil sector. Requirements will evolve as Blue UAS capabilities continue to mature.

## 5.8 Guidelines, Policies, and Procedures

Guidelines, policies, and procedures are distributed throughout this document and in the separate volume, the "Beyond Part 107" document. Within this volume, the reader will find explicit and implied guidelines, policies, and procedures in several sections and corresponding Appendixes:

- Section 5.2: Disaster Research – Case Studies - Historical Disaster Characterization, and the corresponding Appendix B
- Section 5.3: MBSE Process Modeling and Diagramming and corresponding Appendix C
- Section 5.4: Use Cases and Usage Challenges, and corresponding Appendix D
- Section 5.5: Safety and Operational Risk Assessment, and corresponding Appendices E and F
- Section 5.6: Concepts of Operations (CONOPS), and corresponding Attachments 1-10

The "Beyond Part 107" document, delivered as a separate document file, is intended as an interpretive and practical reference for use by first responders. For each section of the Part 107 regulation, the volume addresses the meaning of the law in plain terms, as well as practical suggestions for its implementation by first responders, based on the experience of this team and lessons learned in performing this research.

### *5.8.1 The Role of the Air Boss*

The Air Boss is a disaster team member whose role is managing crewed aircraft and UAS in an emergency response environment in a safe and regulatory approved manner. He can be a former aviator, safety officer, Air Traffic Controller or Disaster Air Specialist. The Air Boss approach is used to protect UAS operations in the NAS and around Crewed Aircraft Operations to assure safety and the integrity of the UAS operations. As soon as practical before an event, the Air Boss team will have been studying the disaster area, closest airport, and the local airspace. He will consult with the incident commander, arrange for any waivers or use of TFR or special constraints from the FAA. The Air Boss may support other air operations or define agreements on who controls certain airspace, determines how hand-offs will be accomplished and defines approach and departure procedures from an area. The Air Boss publishes easily understood NOTAMS and a Mishap Response Plan per the response. And finally, the Air Boss is responsible for any incidents that may take place during operations.

The Air Boss will also serve as the airspace manager to all UAS operations in the LAANC, COA, or Part 107 approved flight areas and will coordinate with FAA accordingly for any crewed operations in the area. The Air Boss will also serve as the liaison to the FAA or other entities for any UAS operation. They will assure compliance to FAA regulatory law and statutes and assure airworthiness compliance of operational aircraft.

The designated Air Boss is responsible for providing clear safety guidance, enabling/conducting safety analysis of new hardware and testing procedures, and enabling a safe work environment. All personnel operating under this plan are responsible for following safety guidance, using common sense, and assessing and mitigating risks. Any unsafe working conditions beyond a team member's ability to quickly fix must be raised to the Air Boss. The Air Boss in coordination with the incident commander is responsible for ensuring that all third-party UAS teams operating in an area have a clear understanding of the boundaries, safety procedures, and loiter areas or holding patterns for emergency procedures.

During actual UAS Operations, the Air Boss will be the final authority on conduct for the UAS being operated and will adhere to established FAA safety policies and procedures. Any UAS operational crewmember may, at any time, call “knock-it-off” to pause any operation to address a safety critical issue.

The Air Boss, as designated by a disaster response organization incident command or the FAA shall:

- Notify the FAA and/or NTSB according to regulatory and agreed-upon requirements.
- Serve as liaison to the FAA and/or NTSB during mishaps.
- Serve as the final approval authority for UAH mishap investigation reports and their release.
- Serve as liaison to interested agencies outside of UAH, including -Public Affairs.
- Determine whether crew involved in a mishap will be required to provide toxicological testing samples, based on recommendations of on-site personnel, extent of damage in the mishap, potential for outside agency involvement, and insurance claim purposes.
- If the toxicological sample process is initiated, the Air Boss will escort all associated personnel to a nearby medical laboratory capable of performing the required tests. Tests will be conducted at UAH expense.
- Serve as the administrator of the initial operational brief prior to each mission assessing readiness, operational areas, weather, and risks.
- Serve as the designator of operational airspace boundaries for each operating UAS and in some cases may serve as the designator of operational airspace boundaries for crewed aviation in a coordinated effort.
- Serve as the direct POC to FAA Air Traffic for UAS operations including communication directly to the appropriate FAA authority as defined hereon and per each operation
- Serve as the mishap reporting authority for any mishap
- Deliver a full mishap report within 30 days of any mishap.
- Provide recommendations to DHS S&T and outside agencies as required to mitigate the risk of further events.
- Coordinate the mishap reporting process and ensure all necessary aspects of this procedure are enacted.
- Serve as Mishap Investigator or liaise with the investigating authority if superseded by the FAA or NTSB.
- Annually review and exercise this procedure to ensure its functionality and effectiveness.
- Ensure all mission safety products and quick reaction checklists are sufficient.
- Maintain a quick reference immediate action plan, and, in case of a mishap or incident involving UAS's in their custody.
- Establish and maintain the integrity of the crash site and ground support equipment while evidence is being collected per this plan.
- Coordinate with the mishap investigation team to collect additional data as requested.
- Ensure that all site personnel involved in the mishap/incident provide information (and medical samples as required) to the investigation team.
- Coordinate logistics for shipping damaged hardware when the investigation team requires an engineering investigation.
- Assist the crews in marking and/or recovering wreckage as requested.

## 5.9 Waivers, Exemptions, and Authorizations

### *5.9.1 Overview*

Small UAS operations for commercial, government, or any non-reactional missions, operators fly under the Part 107 rule (14 CFR Part 107 Small Unmanned Aircraft Systems). There are some operations not covered by Part 107 rules and these require a waiver. Note that changes can occur to those operations that require a waiver. For example, effective April 21, 2021, the Operations over People rule allows operators under Part 107 regulations to fly at night, over people, and moving vehicles if the operator meets the requirements as defined in the rule. Links with more details include: an Executive Summary of the rule that amends the existing 14 CFR Part 107 along with the rule at the Federal Register: 86 FR 4314.

This report provides details on the Part 107 authorization process, where a waiver is required to support a sUAS Part 107 operations, and details on the SGI process. In addition, a summary of the FAA orders is included that provide reference material on the FAA's guidelines and procedures specific to sUAS operations including sections relevant for disaster response and preparedness missions.

### *5.9.2 Part 107 Waivers*

For those flying as a remote pilot under the Part 107 rule, a waiver can be requested from the FAA to approve certain operations outside of the 14 CFR Part 107 sUAS regulations, see FAA site for a description on the process for a Part 107 waiver. This would allow an operator to deviate from certain rules under the Part 107 regulations with demonstrations that the operator is fly safely in the NAS using alternative methods.

There is a list of operations that can be waived provided by the FAA. Note that amendments to the Part 107 rule do occur, such as the April 2021 the Operations over People rule, and as such an operator should always check to determine which operations can be waived, which do not need a waiver, and which cannot be waived.

The FAA provides guidance and application instructions to support those requesting Part 107 waivers. The approval guidance material (waiver evaluation standards) provides information on the factors considered during the review of a Part 107 wavier application while safety guidelines and waiver application instructions together provide additional reference material to support an organization and/or operator in the Part 107 waiver process.

The FAA provides details on the process to apply for a waiver. Step 1: Determine your needs; Step 2: Log into DroneZone; and Step 3: The Decision. An operator will use the FAA's DroneZone to complete their application using their guidelines and instructions to support the operator in their application process. The FAA states on the website, circa October 2021, that they aim to review and provide a decision within 90 days of submission. Issued Part 107 waivers are available online at the FAA site so that any operator can search for any waiver, past and current as well as search by waivered regulations. This information provides, per waiver, details on the applicant [person and organization], listed waived regulations, and provisions (standard and special) included in the waiver application.

#### 5.9.2.1 Part 107 Waiver Example: 107W-2020-04368

This is a Part 107 waiver received by Nicholas Adkins, University of Alaska Fairbanks. Operations authorized under this waiver are stated as "Small unmanned aircraft system (sUAS) operations beyond the visual line of sight of the remote pilot in command (PIC) and Visual Observer (VO), in lieu of visual line of sight (VLOS)”. This waiver supports waving the following regulations:

- 14 CFR 107.31 – Visual line of sight aircraft operation,
- 14 CFR 107.33(b) and (c)(2) – Visual Observer

There are 37 special provisions included within the waiver approval and these are laid out in the accompanying pages. The full waiver can be found at 107W-2020-04368

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

**CERTIFICATE OF WAIVER**

ISSUED TO

**Issued To: University of Alaska Fairbanks**
**Responsible Party: Nicholas Adkins**
**Waiver Number: 107W-2020-04368**

ADDRESS –

**Address:**
**2160 Koyukuk Dr.**
**Fairbanks, AK 99775**

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED

Small unmanned aircraft system (sUAS) operations beyond the visual line of sight of the remote pilot in command (PIC) and Visual Observer (VO), in lieu of visual line of sight (VLOS).

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

**14 CFR § 107.31 — Visual line of sight aircraft operation,**
**14 CFR § 107.33(b) and (c)(2) — Visual observer,**

**STANDARD PROVISIONS**

1. A copy of the application made for this certificate shall be attached to and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Administrator of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein.
4. This certificate is nontransferable.

NOTE—This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

**SPECIAL PROVISIONS**

Special Provisions Nos. 1 to 37, inclusive, are set forth on the attached pages.

This Certificate of Waiver is effective from December 10, 2020, to December 31, 2024, and is subject to cancellation at any time upon notice by the Administrator or an authorized representative.

**BY DIRECTION OF THE ADMINISTRATOR**

EVERETTE C ROCHON JR

Digitally signed by EVERETTE C ROCHON JR
Date: 2020.12.10 12:44:21 -05'00'

**General Aviation and Commercial Division, AFS–800**

Figure 12: Example Certificate of Waiver

### *5.9.3 Part 107 Authorizations*

Authorizations are provided through the LAANC. These are requested for single or limited number of operations and conducted over a short period (< 6 months). This LAANC system automates the application process for the operator to obtain approval for their flight operations. An operator will make a request for flight operations through the LAANC system. Requests are checked against a suite of airspace data sources and if approved, the operator will receive an authorization in real-time.

Based on the location of an operator's mission and the altitudes to be flown, an operator will examine the relevant UAS Facility map using the LAANC system through a FAA approved UAS service supplier. Depending on their location and altitude, the small UAS operators flying under Part 107 rules may be given automated airspace authorizations. LAANC will support the operator if their required altitude is above the ceiling defined in the UAS Facility map for the location of their operations or if the operations request a Part 107 above 400 ft above ground level.

#### *5.9.4 Certificates of Waiver or Authorization (COA)*

Certificates of Waiver or Authorization are awarded by the FAA to a public operator for specific uncrewed aircraft activity. The FAA will perform an operational and technical review of the COA application. The FAA provides an online platform for those operators when submitting their application. Specific information is required from the operator during the submission process.

There are 74, at the time of writing (October 2021), publicly available approved COA's that an operator can download and review. These are catalogued by the organization granted the COA and therefore all COAs per organization are included together in one file. All documents submitted in the COA application are included.

#### *5.9.5 Special Governmental Interest (SGI) Process*

Organizations responded to a natural disaster event or other emergency situations maybe be able to obtain expedited approval for operations through the SGI process. The SGI process supports operations where public and in select cases civil UAS operations may be needed to support special activities.

More can be found in FAA Order JO 7210.3C under Section 21-4-7. The SGI process will be managed by Systems Operations Security. It accommodates real-time application requests that will directly support a UAS operation benefiting a critical public good and addressing exigent circumstances.

To request a waiver through the SGI process, an operator must be a Part 107 remote pilot or have an existing COA. To submit for a waiver, an operator should complete the FAA Emergency Operation Request Form (in word format) and send to the FAA's System Operations Support Center (SOSC) at 9-ator-hq-sosc@faa.gov. If approved, an amendment is added to an existing COA or Remote Pilot Certificate that authorizes the operator too fly under certain conditions for the specified operation.

#### *5.9.6 Federal Aviation Administration Orders*

##### 5.9.6.1 Overview

To support those operators examining the need for an authorization, Part 107 or SGI waiver, current FAA orders are useful reference material on their guidelines and procedures. Current FAA order are available online at https://www.faa.gov/air_traffic/publications/, with some available as PDF and others as interactive HTM pages. Amendments and updates do occur to these orders. Therefore, keeping an up-to-date link to the corresponding order will provide the reference material on FAA's guidelines and procedures to support an operator in understanding how disaster response flight regulations are evaluated for operational requests such as Part 107 waivers and/or the rationale behind a TFR issuance and the corresponding restrictions in place.

Below are details on two FAA orders of interest for UAS disaster response and preparedness operations: JO 7200.23C (effective on September 6, 2021), that focuses on Section 44809, 14 CFR Part 107, sUAS and 14 CFR Part 91, COA applications; and FAA Order JO.7210.3CC (effective on June 17, 2021) that focuses on the day-to-day operation of FAA facilities and offices.

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#### 5.9.6.2 FAA Order JO 7200.23C

Effective September 6, 2021 [Cancels FAA Order 7200.23B that was effective on July 16, 2020]

Below are the pertinent chapters, including the title and page numbers in the 7200.23C order.

- Chapter 2. Processing of DroneZone Section 44809 Authorization Requests, Pages 4 – 6
- Chapter 3. Processing of 14 CFR Part 107.41 Airspace Authorization Request, Pages 7 – 11
- Chapter 4. Processing of 14 CFR Part 107 ATO Operational Waiver Requests, Pages 12
- Chapter 5. Processing of 14 CFR Part 91.113 Waiver Requests, Pages 13 – 14
- Chapter 6. Part 91, Certificate of Waiver or Authorization (COA) Processing, Pages 15 – 18

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#### 5.9.6.3 6.3. FAA Order JO.7210.3CC

Effective June 17, 2021 [Adds requirements to FAA Order JO 7210.3]

Below are sections of interest in Order JO.7210.3CC, including title and page numbers. Note that the FAA provides an interactive HTM for this order and the web-link for each section is provided.

**Part 1. Basic**

Chapter 5. Special Flight Handling – Section 5. 14 CFR Part 91, UAS Operations

Shortcut in PDF: 5-5-1

Pages 167 – 169

Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap5_section_5.html

**Part 2. Air Route Traffic Control Centers**

- Chapter 12. National Programs – Section 9. Low Altitude Authorization Notification Capacity

  Shortcut in PDF: 12-9-1

  Pages 295 – 296

  Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap12_section_9.html

- Chapter 12. National Programs – Section 10. UAS Facility Maps (UASFM)

  Shortcut in PDF: 12-10-1

Pages 297 – 301

Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap12_section_10.html

**Part 6. Regulatory Information**

- Chapter 19. Waivers, Authorizations, and Exemptions – Section 1. Waivers and Authorization

  Shortcut in PDF: 19-1-1

  Page 425 – 429

  Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap19_section_1.html

- Chapter 19. Waivers, Authorizations, and Exemptions – Section 6. 14 CFR Part 107, sUAS Operations

  Shortcut in PDF: 19-6-1

  Pages 439 – 440

  Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap19_section_6.html

- Chapter 20. Temporary Flight Restrictions – Section 1. General Information

  Shortcut in PDF: 20-1-1

  Page 441 – 442

  Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_1.html

- Chapter 20. Temporary Flight Restrictions – Section 2. Temporary Flight Restrictions in the Vicinity of Disaster/Hazard Areas (14 CFR Section 91.137)

  Shortcut in PDF: 20-2-1

  Page 443 – 445

  Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_2.html

- Chapter 20. Temporary Flight Restrictions – Section 3. Temporary Flight Restrictions in National Disaster Areas in the State of Hawaii (14 CFR Section 91.138)

  Shortcut in PDF: 20-3-1

  Page 447

  Web: https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_3.html

- Chapter 20. Temporary Flight Restrictions – Section 4. Emergency Air Traffic Rules (14 CFR Section 91.139)

Shortcut in PDF: 20-4-1

Page 448

Web:
https://www.faa.gov/air_traffic/publications/atpubs/foa_html/chap20_section_4.html

**Part 7. Systems Operations Security**

- Chapter 21. Operations Security: Tactical, Special, and Strategic – Section 4. Supplemental Duties

# 6 LITERATURE SEARCH RESULTS

## 6.1 Incident Command Structure (ICS) - (IS 100, IS 200, IS 700, IS 800, IS-5A, IS3)

The ICS established by the National Incident Management System (NIMS) is defined by the US Department of Transportation (DoT) as, "a systematic tool used for the command, control, and coordination of emergency response. ICS allows agencies to work together using common terminology and operating procedures controlling personnel, facilities, equipment, and communications at a single incident scene (U.S. Department of Transportation, Federal Highway Administration (February 2006))." The organizational structure of ICS is depicted in the Figure 13.

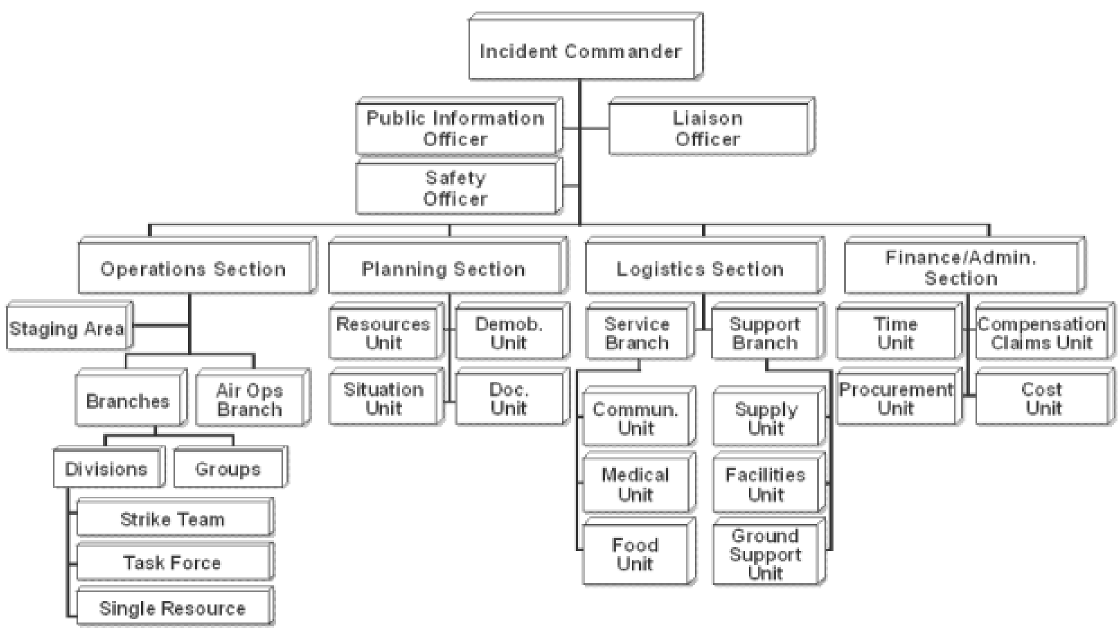


Figure 13: Incident Command Structure

The breakdown of tasks for each element within the structure are outlined below.

- **Incident Commander:** The incident commander is the overall authority for the incident. The Incident Commander is responsible for: setting priorities, determining incident objectives, ensuring incident safety, coordinating command and staff activities, completing after-action reports, authorizing information release to the media, and ordering mobilization/demobilization as needed.

- **Command Staff (Officer):** The command staff reports directly to the incident commander. The command staff carries out activities needed to support the incident commander such as, interagency liaison, incident safety, and public information.
- **Section:** A section is an organizational level that has responsibility for a major functional area within incident management i.e. operations, planning, logistics, and finances/administration.
- **Branch:** A branch has functional and/or geographical responsibility for major aspects of incident operations. A branch is identified by Roman numerals or by functional area.
- **Group:** A group divides the incident management structure into functional areas of operation.
- **Unit:** A unit is responsible for planning, logistics, or finance/administration related to a specific incident.
- **Task Force:** A task force is any combination of resources assembled to support a specific mission or operational need. All resource elements within a Task Force must have common communications and a designated leader.
- **Strike Team/Resource Team:** A strike team is a set number of resources of the same kind and type that have an established minimum number of personnel, common communications, and a designated leader.
- **Single Resource:** A single resource is an individual, a piece of equipment and its personnel complement, or a crew/team of individuals with an identified work supervisor that can be used on an incident.

### 6.2 National Incident Management System (NIMS)

NIMS provides guidance for effective incident management to all levels of government, nongovernment, and private organizations. NIMS clearly defines the necessary operational systems such as the ICS, EOC, and Multiagency Coordination Groups. These systems guide personnel on how to collaborate, respond, and recover from major to minor incidents/disasters. Because the jurisdiction and authority of organizations involved in disaster response may vary, NIMS provides a common framework to consolidate diverse capabilities. NIMS embodies and embraces three building blocks and three guiding principles. These building blocks and guiding principles are listed and defined below as reported by FEMA in the National Incident Management System document written in October of 2017 (FEMA (October 2017)).

NIMS Building Blocks:

- **Resource Management** describes standard mechanisms to systematically manage resources, including personnel, equipment, supplies, teams, and facilities, both before and during incidents in order to allow organizations to more effectively share resources when needed.
- **Command and Coordination** describes leadership roles, processes, and recommended organizational structures for incident management at the operational and incident support levels and explains how these structures interact to manage incidents effectively and efficiently.

- **Communications and Information Management** describes systems and methods that help to ensure that incident personnel and other decision makers have the means and information they need to make and communicate decisions.

NIMS Guiding Principles:

- **Flexibility** allows NIMS to be scalable and, therefore, applicable for incidents that vary widely in terms of hazard, geography, demographics, climate, cultural, and organizational authorities.
- **Standardization** is essential to interoperability among multiple organizations in incident response. NIMS defines standard organizational structures that improve integration and connectivity among jurisdictions and organizations. NIMS defines standard practices that allow incident personnel to work together effectively and foster cohesion among the various organizations involved
- **Unity of effort** means coordinating activities among various organizations to achieve common objectives.

## 6.3 Emergency Management Agencies

Emergency management agencies like DHS, FEMA, Office of Response and Recovery, and Response Directorate deploy UAS for aerial imagery in disaster response. However, barriers like public perception, current FAA regulations, and a general lack of organizational policy structures complicate the operation of uncrewed aircraft for disaster response. Steps have been made to ease the conflict of privacy in domestic UAS operations. DHS has assigned the Office for Civil Liberties and the Privacy Office to lead a working group that aims to ensure no violation of individual privacy rights. FAA restrictions on the operation of UAS significantly limit the possible applications of such systems for disaster response (Price, D. E. (March 2016)). However, the new FAA updates (effective April 21, 2021) to Part 107 rules and regulations regarding night operations and flights over people will significantly benefit the operation of UAS in disaster response scenarios.

## 6.4 National Disaster Declaration

A national disaster declaration is defined as a formal statement by a state or local government's chief official that a disaster or emergency situation exceeds their response capabilities. A disaster declaration can be established before or after a severe emergency. There are two general types of disaster declarations: major disaster and emergency. Major disaster declarations are generally requested for the most severe of disasters when long term recovery assistance is needed. Conversely, emergency declarations are generally requested when no long-term recovery assistance is required (Parker, LLP (n.d.)).

According to the *Robert T. Stafford Disaster Relief and Emergency Assistance Act, May 2019*, national disaster declarations will abide by the following protocol (FEMA P-592):

- The governor of an affected state shall request the U.S. President establish a major disaster declaration. This request is based on the effective response capabilities of state and local governments. This means that the disaster is of such severity and magnitude that federal assistance is needed. As a prerequisite, the governor of the affected state shall take appropriate action under state law and direct the execution of the state's emergency plan. This means that the governor shall supply information on the amount of state and local resources that will be allotted for the response.

### 6.5 Critical Infrastructure Disaster Area (CIDA)

There is not an abundant amount of information that is publicly available regarding Critical Infrastructure Disaster Areas (CIDA); CIDA is a new concept. However, the concept of CIDA is similar to that of FAA's LAANC. LAANC provides automated airspace authorizations at pre-approved altitudes through FAA approved vendors (Federal Aviation Administration (29 September 2021)). In a similar sense, CIDA aims to provide flight authorization to UAS operators in airspace around critical infrastructure disaster areas. Disaster response agencies increasingly want to operate UAS platforms over disaster areas. The FAA has approved COA waivers to allow disaster UAS operations for the United States Northern Command (NORTHCOM), CONR-1AF, and other state and federal agencies (FAA-Disaster Airspace Management (July 2012)). UAS disaster operations are time critical, therefore, pre-existing COAs or expedited COA processes can be established with the FAA. Additionally, the FAA has established a specialized UAS Program Office (UASPO) to manage requests for COAs. However, CIDA would offer more opportunities for UAS disaster response operations within the national airspace.

### 6.6 Disaster Support Reservation System (DSRS)

A Disaster Support Reservation System (DSRS), similar to UAS Service Supplier (USS), operates as a system to support UAS drone operations for disaster response. DSRS is a new concept, however, USSs are currently used to support Uncrewed Traffic Management (UTM) services. Such services help enable the safe, secure, and efficient use of the NAS. USSs provide communication channels between UAS operators and authorities. They offer resources for monitoring terrain, weather, and population, as well as networks for sharing operational data to ensure situational awareness within a geographical area and its airspace (SKYGRID (2 April 2020)). In a similar sense, DSRS will provide UAS first responders a tool to operate safely in airspace surrounding a disaster area.

### 6.7 Wildfire Pod Seeding using UAS

According to the Center for Disaster Philanthropy, as of October 2021, the National Interagency Fire Center has reported 47,602 wildfires across the country. 6.5 million acres were destroyed severely harming the surrounding ecosystems. A potential solution to replace these ecosystems is through pod seeding using UAS. Pod seed dispersal using drones offers many advantages in reforestation efforts. UAS pod seeding creates an efficient, robust, and safe alternative to classical tree planting. UAS dispersal of pod seeds for reforestation is currently being used by a company named DroneSeed. DroneSeed is the first and only U.S. company to receive an FAA waiver to use drone swarms to reverse wildfire destruction. Each heavy-lift certified drone carries enough seedlings to plant ¾ of an acre per flight. Additionally, DroneSeed's drones can spray invasive plants and remotely identify the best places for seed packets (Coldewey (29 September 2021)). UAS technology like DroneSeed offers a new tool for increasing the pace and scale of reforestation efforts across the country.

### 6.8 Precision Fire Retardant Submissions using UAS

Current and near future technological developments of uncrewed systems can deliver breakthroughs in the application of UAS for precision firefighting. Drones can provide firefighters with a means to locate, track, and cease wildfires. In 2020, the USDA added a firefighting drone to its wildfire arsenal. The fire-containing drone is supplied with 400 "eggs." When commanded, the drone punctures and injects the "eggs" with highly flammable glycol. Once injected, a chemical reaction turns the "eggs" into firebombs. Using onboard sensing and AI, the drone accurately drops these bombs burning any fuel in the wildfire's path (Reinke (20 November 2020)).

In the near future, drone swarms could be used for precision firefighting. A drone swarm for fire suppression activities concept was proposed by (Ausonio et al. (7 March 2021)). This concept proposes a swarm system that can automatically replace exhausted batteries, ensure operational continuity, and allow for multiple extinguishing liquid refills. A system such as a swarm has considerable advantages to fighting fires. A swarm can be deployed at any time of day, in low visibility, and guarantee a uniform diffusion of extinguishing liquid. Advanced swarms could potentially remotely identify critical areas of concern (i.e. critical infrastructure) and autonomously target an area based on priority level (Ausonio (7 March 2021)).

## 6.9 Real-Time Aerial Image Compositing

Traditional aerial image compositing is very common in disaster response scenarios today, but usually involves a large dataset of images to be collected by an aircraft, offloaded to a computer post-flight, and subsequently processed and stitched together to form a large photomosaic. This process often takes hours, losing valuable time for effective emergency response. If it were possible to do this computation in real-time as images are collected by the aircraft, this technology would be significantly more valuable. Researchers at the University of Canterbury in New Zealand published a research paper on what they call RT-AIM, or Real-Time Aerial Image Mosaicing, which functions similarly to traditional aerial image compositing but takes advantage of the latest, fastest computer vision algorithms in order to enable real-time compositing. At a high level, their system first finds distinctive features in each image and indexes them, using a FAST corner detection algorithm and a hierarchical "Bag-of-Words" database. This step takes 4ms per image on average. They then use the BaySAC algorithm to determine the correct positions, orientations and necessary transformations to place a given image relative to the rest of the collected images. This project was intended to expand the field of view of an aircraft camera in real-time to aid the operator, so these calculations are performed on a video feed rather than an image set used to produce a static map, but this technique could be applied (likely even more effectively) to the production of static maps of disaster areas.

## 6.10 Air Boss

There is no formal role under the name Air Boss, however, the position will be similar to that of the FEMA Air Operations Branch Director (AOBD). The AOBD supervises, prepares, implements strategies, and provides logistical support for all incident response air operation activities (National Wildfire Coordinating Group (27 September 2021)). Similarly, the Air Boss would be responsible for ensuring that all third-party UAS teams operating in an incident area have a clear understanding of the boundaries, safety procedures, and loiter areas/holding patterns for emergency procedures. An Air Boss would serve as a mediator between UAS operations and the FAA ensuring regulatory law compliance during missions. The position would conduct aerial surveys of a UAS incident operation's airspace, complete any necessary hazard maps, and brief all first responder pilots in command before dispatch.

## 6.11 Automated Air Boss

An automated Air Boss would operate similarly to a USS for the application of disaster response. Uncrewed service suppliers are helping shape the future of the drone and aviation industry. A service supplier can provide UAS operations with valuable insight including airspace regulations, crewed and uncrewed air traffic, weather, and TFRs. Uncrewed service suppliers like AirMap are leading the effort in establishing an 'Automated Air Boss' for disaster response. AirMap's AirBoss system provides first responders and public safety officials with real-time insight, imagery, and intelligence in the event of an emergency. Additionally, AirBoss provides flight planning and automation, image collection for real-time and post flight analysis. AirBoss's algorithm and AI capabilities consider TFRs and no-fly zones to ensure safe operations (Macquarie Technology (n.d.)). Additional features for an automated air boss solution to UAS disaster response management might be automated flight authorizations for disaster response, real time generation of critical response disaster areas, automated emergency dispatch and return-to-home.

## 6.12 Machine Learning Applications

Machine learning technologies can assist in making accurate predictions of many disaster event factors, such as: when a disaster will hit, how destructive it will be, what areas will be impacted most severely, vulnerable infrastructure, potential power outage areas, necessary resources for response, and cost of the response effort. Machine learning essentially trains a computer to process historical data and develop insights which far exceed what a human brain can compute. Research groups are already employing machine learning to predict power outages from hurricanes or other severe weather events which has provided key information to improve decision making. Machine learning is also being used to gather and process sentimental data from Twitter during disaster events in order to determine public needs and opinions regarding disaster response, such as which relief supplies are most needed. This data is also being used to create detailed maps of disaster events, localizing specific details using images and descriptions crowd-sourced from Twitter.

## 6.13 Blockchain

"Blockchain is a shared, immutable ledge that facilitates the process of recording transactions and tracking assets in a network." These assets can be something tangible such as money or property, or intangible such as intellectual property, patents, etc. Blockchain provides immediate, shared, completely transparent information that can only be accessed by permissioned network members. When a transaction occurs, it is recorded as a data block in the blockchain. As ownership changes hands, the block confirms the exact time and sequence of transactions, and is linked securely to the adjacent blocks in the chain to prevent any block from being altered or rearranged. Each new block in the chain strengthens the verification of the previous block, and renders the chain tamper-proof.

Researchers at Deakin University are developing a platform for drone-assisted networking for disaster response utilizing blockchain and 6G. Their research is focused on the reduction of latency while using blockchain technology for data collection as well as energy consumption when deployed on-board a UAS. By deploying this technology aboard UAS, they aim to gather large amounts of imagery and location data from multiple aircraft during a disaster scenario, and employ machine learning in order to develop a detailed model of a disaster area utilizing a large dataset derived from multiple sources.

### 6.14 Machine Learning

Machine Learning is a form of artificial intelligence which is focused on utilizing large datasets and many different algorithms to imitate the way that humans learn. There are three distinct variants of machine learning: supervised, unsupervised, and semi-supervised. In supervised machine learning, labeled datasets are used to train the algorithms with the objective of accurately predicting outcomes or classifying data. Unsupervised learning, on the other hand, uses unlabeled datasets and aims to organize them for better analysis. It is a valuable tool for discovering similarities and differences in information. Finally, semi-supervised learning is a mixture of supervised and unsupervised learning which uses a small, labeled dataset to guide classification and processing of a larger unlabeled dataset.

The terms deep learning and neural networks are also commonly used when discussing machine learning, but they are actually both subsets - deep learning involves automating the data collection process by being able to ingest unstructured and varied datasets, whereas traditional machine learning requires an organized, labeled dataset involving more human intervention to perform. Neural networks aim to mimic the human brain through a set of algorithms, and are composed of four main components: inputs, weights, biases, and outputs. Each set of these components is referred to as a node - when the output of one node meets the activation criteria of a connected node, data is transferred to that node which will conduct its own operation on the data, and so on.

### 6.15 Morphing Aerostructures

Currently there are no industry examples of morphing aerostructures for the application of emergency response. Many morphing concepts such as, morphing wings (Li, D., et al. (20 June 2018)) and frames (Falanga, D., et al. (November 2018)), (Vargas, G. O., et al. (9 July 2015)) have been successfully tested. However, there have been no major commercial breakthroughs for these technologies. As UAS emerge as solutions for supplementary emergency response support, increased aircraft endurance and profile manipulation (benefits of morphing aerostructures) will enhance capabilities of such operations. Enhanced endurance will extend the length of UAS emergency response missions. Profile manipulation allows an aircraft to broaden the ability of a UAS to conduct search and rescue operations.

## 7 CONCLUSIONS AND WAY AHEAD

This research provided the foundational and fundamental concepts for first responders to utilize uncrewed aircraft systems effectively and efficiently in a disaster response.

The major sections of this research provided an insight into the state of UAS operations across the first responders in the United States, documents pictorially, the communication paths as they exist today for regulatory and consistent communication across the incident command structure. Further, there are detailed concepts of operations, checklists, waivers, and operational risk assessments provided for each type of disaster. If a first responder is to respond for a specific disaster the contents of this research will specify to him the details he needs to select aircraft, sensors, and understand the limitations and advantages of capabilities of that solution to respond to that specific event. The report also provided an evaluation of new technologies and processes to complement operations in a more effective and efficient manner. Those kinds of technologies include items like disaster based uncrewed aircraft systems traffic management, the use of an air boss to coordinate airspace operations across crewed and uncrewed technologies and advanced multi-band sensors.

A document entitled Beyond Part 107 for First Responders was developed to provide an interpretation and clarification of Part 107 laws. Uncrewed Aircraft Systems operators with many years of experience have developed this document to aid first responders in their understanding of Part 107. This book should be used as a guide to assist in understanding the law and responding effectively according to the law while other regulatory capabilities may be put in place for the disaster. Please note in many cases Part 107 may be the only FAA operational permission for the entire disaster.

This research informs the next phase of research supporting the execution of exercises based on specific disasters. For example, train derailment, hurricanes, flooding and tornadoes, earthquakes, and wildfires. It is important to note that the next phase of research will refine the data products of this research by executing them with first responders and the FAA UAS test sites.

A tribute goes out to this excellent research team. The research team includes Oregon State University, North Carolina State University, New Mexico State University, Mississippi State University, the University of Alaska in Fairbanks, the University of Vermont and the lead institution for this research, the University of Alabama in Huntsville. Principal investigators from each of the schools had unique capability that allowed their composites of expertise to be provided to the FAA and first responder community. The team appreciates the contributions and leadership of the FAA, the ASSURE program, and the excellent peer review team from across the United States. The peer review team included: The Department of Interior, National Aeronautics and Space Administration (NASA), Federal Emergency Management Agency (FEMA), National Oceanic and Atmospheric Administration (NOAA), National Institute of Standards (NIST), and the FAA emergency operations organization. Their leadership helped guide these results.

# 8 RESPONSES TO RESEARCH TASK PLAN QUESTIONS

The Research Task Plan that defined this effort included a number of questions focused on the hoped-for results of this research. To assist the reader, those questions and the responses to them are presented below:

### 2.1.A What are the use cases for the different disasters preparedness and response efforts that UAS can help facilitate?

See Section 5.4 - Use Cases and Usage Challenges as well as Appendix D - UAS Use Cases and Usage Challenges.

UAS facilitates all existing disaster preparedness and response use cases in which occupied aircraft have been traditionally employed. In addition, UAS are opening up future cases for which occupied aircraft have not yet been utilized, such as serving as a communication relay network when first responders enter a skyscraper.

Across the board, the survey found that most UAS are used for data collection activities supporting disaster response. These activities vary widely, from gaining initial situational awareness during an emergent crisis (from hurricanes to hazardous materials incidents) to creating detailed photogrammetric maps of disaster areas to support rebuilding efforts.

The research found that drone users have highly different levels of technical knowledge and data processing expertise, ranging from minimal expertise to experience with highly sophisticated drone data collection and analysis operations. Organizational approaches for collecting drone data, processing it, sharing it, and storing it are highly heterogeneous. While small drones produced by popular Chinese drone maker DJI were the most common hardware choice among interviewees, software approaches to flight planning, data processing, analytics, and data storage vary immensely. There is no single, widely accepted software, product, or workflow for accomplishing data collection and analysis goals.

### 2.1.B How is coordination done today with FEMA/DOI/DHS to ensure safe operations after a disaster?

Coordination can vary significantly by FEMA region. Some regions have clear, established policies and procedures that have been rehearsed, while other regions' coordination efforts are less developed. The research uncovered that coordination among federal agencies is not the most urgent issue when it comes to the challenges of ensuring safety in the nation's airspace during a disaster. The larger issue is that multiple organizations may all seek to operate UAS during a disaster in the same airspace, creating challenges and risks related to sharing that airspace safely. This includes a variety of stakeholders with varied goals and technical knowledge, such as state and local governments, tribal governments, utilities, insurance agencies, volunteers, academic institutions, the media, and members of the general public; the research found no examples of technologies or frameworks that enable all of these entities to work in the same airspace safely and effectively.

There is no single, widely accepted set of written best practices or guidance for drone use in disaster response. Organizations are largely left to develop their own best practices, a process that is often done without collaboration with other disaster response drone users. Furthermore, there is no standardized and widely accepted training program or certification that covers drone operations during disasters. As a result, the interviewee's knowledge of best practices, regulations, and coordination of Standard Operating Procedures (SOP) is extremely varied.

In the area of airspace deconfliction, the reader is encouraged to refer to Sections 5.8.1, 6.11, and 6.12 dealing with the role of the Air Boss, as well as 6.5, which deals with the subject of UTM.

### 2.1.C What are the common risks for the use cases? What are the mitigations to those risks to ensure safe operations for UAS?

See Section 5.5 - Safety and Operational Risk Assessment as well as Appendix E – Operational Risk Assessment (ORA).

The major direct risks associated with operating UAS during a disaster can be divided into two general categories. One is a system failure resulting in the UAS striking personnel on the ground. The second is an in-flight collision with occupied aircraft. Risk management procedures are crucial for mitigating these risks and ensuring the safe operation of UAS during a disaster. While UAS platforms have an excellent safety track record, issues may still arise. Efforts should always be made to minimize flights over people. To avoid collisions, either with occupied aircraft or other UAS platforms, airspace coordination is paramount. The team determined the most successful examples of airspace coordination occur when there is an Air Boss, or a single entity that oversees airspace management and coordination. The wildfire-fighting community excels in this regard because they practice and exercise air operations annually. The frequency of wildland fires ensures that they are executing what they have rehearsed on a regular basis and also allows participants to think creatively about drone applications.

Another key risk associated with operating UAS during disaster is that of drone data being used in inappropriate or dangerous ways that can pose security threats. Please see the question related to cybersecurity for further comments.

### 2.1.D What are the characteristics of the optimum UAS(s) for disaster preparedness?

See Section 5.4 - Use Cases and Usage Challenges as well as Appendix D - UAS Use Cases and Usage Challenges. Analysis of past case studies has summarized the details of each UAS operations and the common aspects included in each mission. This was used to develop the common features needed in the CONOP template so that UAS can be optimally used to collect the data needed to support decision making during disaster response as well as for preparedness missions.

There are no single characteristics that define the optimum UAS for disaster preparedness. The experience of the operator, data and information needs, safety, equipment cost, and airspace coordination all factor into UAS platform selection. In many cases, the optimum UAS will be the one that the operator is most familiar with, fits into their budget, and can meet the minimum information requirements in the timeliest manner with the least risk.

### 2.1.E What lessons were learned from the use case demonstrations?

The value of effective airspace coordination was the most important lesson learned from the use case demonstrations. The research found that during disasters, when the airspace was uncoordinated, it resulted in the grounding of UAS platforms, often for days. This substantially curtailed effective implementation designed to save lives and speed recovery.

Some interviewees noted that federal restrictions on the use of Chinese-made DJI products (introduced after 2017) presented major obstacles to their drone programs. As of this writing, DJI products are still much less expensive, easier to use, able to operate with a larger number of relevant software tools (like photogrammetry and mapping software), and easier to obtain than US-made drones that satisfy federal requirements. Interviewees operating with limited budgets and with specific needs reported considerable challenges with finding and affording equivalent US-made drone products to replace existing fleets of DJI UAS.

A substantial number of use case demonstrations are planned to take place under A.52.

### 2.1.F What should future coordination with FEMA/DOI/DHS look like with UAS integrated into the NAS?

Effective coordination needs to go far beyond the federal agencies involved in disaster response. It needs to extend to all entities operating within the airspace. This includes a variety of stakeholders with varied goals and technical knowledge, such as state and local governments, tribal governments, utilities, insurance agencies, volunteers, academic institutions, the media, and members of the general public. The best way to achieve this is to ensure that plans address airspace coordination, that a single entity or individual is responsible for airspace coordination, and that organizations that envision themselves operating in the airspace during a disaster carry out regular integration exercises. The need for guidance and support for these activities at the federal level was frequently cited by interviewees.

In the area of future coordination with FEMA/DOI/DHS, the reader is encouraged to refer to Sections 5.8.1, 6.11, and 6.12 dealing with the role of the Air Boss, as well as 6.5, which deals with the subject of UTM.

### 2.1.G What are the considerations for secure Command and Control-C2 links?

Secure command and control links are ideal. However, this does not come without a cost. Security can compromise interoperability and communication, particularly in disasters in which nongovernment entities, such as utilities and academic institutions play a crucial role. More secure C2 links may also result in lower latency, which may present challenges during disaster situations that are particularly fast-moving or are developing quickly.

### 2.1.H What are the cyber security considerations?

When UAS data are collected during a disaster, there is a risk the data could be used in an inappropriate or harmful way. UAS can collect highly detailed, high-resolution data that may contain personally identifiable information. If drone data is improperly secured or shared with the wrong parties, drone data collected during a disaster could be used by bad actors to target individuals, private property, and organizations. In general, the research found that while drone users during a disaster are generally at least somewhat aware of these risks, there is no single or standardized approach for protecting data, reviewing data for potential PII issues, or addressing data harms/misuse.

As mentioned previously, US government restrictions on the use of Chinese-made DJI drone products have presented considerable challenges to some of the interviewees. The potential cybersecurity risks of using DJI products (and other Chinese-made small UAS) will need to be weighed against the reality that approved US-made UAS products with similar functionality remain expensive, often do not have equivalent features, and can be challenging to obtain.

**T1.A What governmental, industry, and non-profit organizations at the local, state and national level are involved in emergency preparedness and disaster response?**

Entities at all levels of government, including federal, state, tribal, and local agencies, are all involved in disaster response. The overwhelming response of the government agencies surveyed was that the use of aircraft, particularly UAS, was likely to increase in future disasters. NGOs and volunteer organizations are increasingly employing UAS for disaster response, as are academic institutions, utility companies, insurance providers, the media, and the general public. Each of these entities brings its own set of goals and approaches to the table, which is why arranging opportunities for communication and planning before a disaster situation is so critical for successful coordination during a real event. Tabletop exercises, field exercises, and joint planning were cited by interviewees as helpful tools for improving coordination.

**T1.B What is the best method of survey to use for disaster supporting organizations?**

The team found that there was no single survey method that proved to be superior based on stakeholder feedback. In order to help ensure that the data collected represented the full array of organizations involved in disaster response and provided the types of insights needed for rigorous research, a multitude of survey tools were employed. These included online surveys, interactive surveys held at regional symposiums, and interviews. Each of these methods has advantages and disadvantages, and the team found tremendous value in taking this synergistic approach to data collection.

**T1.C Which disaster responders need to be surveyed relative to disaster relief using UAS?**

The survey approach focused on gathering information from a broad swath of disaster responders, including federal, tribal, state, and local government agencies, NGOs, academic institutions, and private sector entities. Speaking to representatives from each of these areas provided a much clearer picture of the opportunities and challenges experienced by those who may deploy UAS technology or use UAS data during a disaster. These organizations must have an input to the survey process for an accurate assessment of all organizations involved.

**T1.D Define the response protocols and procedure for a wildfire, earthquake, volcano, tornado, flood, hurricane, or a human-made disaster response.**

See Section 5.6 - Concepts of Operations (CONOPS) and Concept of Operations (CONOPS) Attachments 1-10, Including Airport Terrorism, Earthquake and Tsunami, Hurricane, Tornado, and Flooding, Oil Spill, Pandemic (Intermediate UAS and sUAS), Train Derailment, Volcano, and Wildland Fires.

**T1.E What hurdles are organizations facing when incorporating UAS into disaster response and recovery?**

Funding, support from leadership, staffing, concerns about safety, training, lack of data processing capability, data storage and sharing issues, airspace coordination, and regulations (federal, state, and local) topped the list of concerns in the survey work.

**T2.A What organizations use manned aircraft for disaster response?**

Occupied aircraft are primarily used by federal and state government entities, with occasional use by local governments. Federal agencies that employ occupied aircraft in a disaster include NOAA, DOI, BLM, US Forest Service, NASA, USACE, National Guard, Navy, Coast Guard, and CAP. Occupied aircraft are also used by utility companies, the media, academic institutions, and volunteers.

**T2.B What is the best methodology to survey the experts to gain the detailed information relative to the way the agencies operate with the FAA and other first responders?**

To gain detailed information, the team found that interviews were the optimal method. This approach provided a way to gain additional information on topics of interest. Interviews also served as a mechanism to engage in a more freeform discussion around certain topics, resulting in information captured that would have not likely occurred in an online survey.

**T2.C What coordination metrics can be measured to assess process improvement?**

See Section 5.3 - MBSE Process Modeling and Diagramming.

**T2.D How do the agencies coordinate and communicate with the FAA?**

Some agencies have extensive coordination with the FAA; others have little to none. For those agencies that engage in disaster response on a regular basis, such as the wildland firefighting community, the process of communication with the FAA is exercised often, and these organizations reported no issues. Other groups, particularly local governments and private sector entities had never communicated with the FAA, and they stated they had no idea how they would. For those organizations who said they had little or no experience communicating with the FAA they said that training, exercises, and dedicated FAA liaison during the disaster would be of help.

**T2.E In each state, what role does state and local government play in a disaster response?**

In any disaster, no matter the size, local government is involved. However, the extent to which state government engages depends on the size and scope of the disaster, regulations, and the capabilities of local government. The role state and local governments play in disaster response varies greatly throughout the United States. These differences fall into two broad categories, jurisdictional authority, and emergency management capabilities with some states being more active in responses and controlling of coordinated efforts across many cities or counties/parishes, etc. Federally recognized tribes are sovereign entities and have jurisdiction over their land in a disaster. Support from external organizations must be coordinated through the tribe in most cases. The governance structure in some parts of the country gives counties/parishes broad authority for emergency management, whereas in others, it falls to the state. Some counties, cities, and municipalities have their own emergency management agencies, whereas others are entirely dependent on the state government for emergency management.

**T3.A What do federal, state, and local governments need in the way of CONOPS and SOPs?**

The need for CONOPS and SOPs varies greatly. Some organizations, particularly federal and state agencies involved in wildland firefighting, have well-established CONOPS and SOPs. Many local entities with long-existing UAS programs also have these in place, while other organizations reported that they lack CONOPS and SOPs. Frequently, those that lacked the resources communicated that CONOPS and SOPs would help them greatly and would enhance their ability to effectively employ UAS in a disaster.

Organizations should also ensure that any CONOPs and SOPs they develop consider issues related to data security, data retention policies, and privacy protection. Currently, very few organizations have CONOPs or SOPs specifically covering these issues. See Section 5.6 on CONOPS development for each disaster.

**T3.B What existing work is being done with respect to UAS CONOPS and TTPs?**

This team has prepared extensive documentation on UAS and TTP. The results may be found in Section 5.6 as well as Attachments 1 through 10.

**T3.C What professional organizations are involved in sharing and disseminating information on UAS for disaster response?**

Professional organizations like AUVSI and other NGOs across the United States help share information about disaster operations across the community. Governmental organizations like CAP, FEMA and FAA offer an important role and capacity for sharing information at large across the responder organizations. Organizations such as DroneResponders regularly hold events that facilitate this type of information exchange as well.

**T4.A How familiar are agencies with the current waiver process? Both the normal waiver and Emergency COA and Special Governmental Issue (eCOA/SGI) processes?**

Most federal agencies are well-versed with emergency COA and SGI processes. The team did encounter one federal entity that had never heard of either of these and was under the impression that the inability to obtain waivers quickly would hamper their ability to employ UAS during disaster response. Every organization that was spoken with was complimentary of the SGI process. This included federal, state, and local agencies along with academic institutions.

**T4.B Which UAS operational waivers are most likely needed in a disaster response?**

See Section 5.9 - Waivers, Exemptions, and Authorizations, also See Section 5.5 - Safety and Operational Risk Assessment as well as Appendix E – Operational Risk Assessment (ORA); Also Appendix D - UAS Use Cases and Usage Challenges.

BVLOS ranked as the highest need. Multiple organizations surveyed involved in wildland firefighting said that the inability to obtain BVLOS waivers in a timely manner substantially impacted their ability to fully capitalize on UAS technology. For disasters in more urbanized areas, flights over people were considered important. A number of interviewees discussed the need for a comprehensive risk assessment in which the risk of the waiver should be balanced with the risk of not having a waiver, which could involve sending a first responder into a dangerous situation that has a much higher risk profile than the UAS waiver.

**T4.C What training or guidance do agencies require with respect to the waiver process?**

One federal entity the team spoke with was not aware of the SGI process. In this instance, the interviewer briefed the entity on the SGI process and pointed them to the FAA web page on SGI, which provided them with the information they needed. Most of the utilities and local governments spoken with said they found the waiver process daunting. Peer-to-peer information exchanges are an effective mechanism for disseminating information. Organizations such as DroneResponders regularly hold events that facilitate this type of information exchange.

**T4.D What stresses might the waiver process face as UAS use expands during disaster response?**

The findings show that the use of UAS is only going to increase in future disasters, potentially at an exponential level. This will likely place an increased strain on the waiver process as the FAA has to balance the request for waivers and potentially competing requests from organizations operating in the same airspace.

**T4.E What technological advancements might negate the need for waivers?**

Remote ID and drone detection technology topped the list of technological advances that would reduce the need for some waivers. A number of those interviewed felt that the technology already existed for safe BVLOS operations, particularly in rural areas. It should be noted that technology should not be seen as a replacement for planning, coordination, and exercises. See also Section 5.7 - UAS Technology Evaluation.

**T5.A What technologies would help improve coordination?**

Remote ID and drone detection were also mentioned as technologies that respondents noted could improve coordination. One idea that surfaced in an interview session, and was endorsed by others, is an online portal in which UAS operators involved in disaster response could upload their flight plans. Once the mission is complete, the area for which they acquired data along with information on the data products. Researchers were surprised to find that on the FEMA remote sensing calls for Hurricane Ida, the UAS collection deck was never presented, only occupied aircraft and satellite collections were shared. A lack of understanding about what UAS operations are occurring and what data are being acquired can result in poor coordination, gaps in coverage, and overlaps in coverage. There is a clear need for a comprehensive approach to remote sensing collection management, similar to the approach employed by the military.

**T5.B What manned use cases can UAS currently replicate, what are the similarities and drawbacks?**

UAS can currently augment or replicate the majority of crewed-aircraft data collection missions, such as post-disaster damage assessment, searching for missing persons, pre-disaster risk assessment, emergency scene situational awareness, and more.

The key advantages of using UAS include:

- UAS flights do not place pilots and passengers at risk compared to crewed alternatives. They present far less risk to people on the ground in the event of a crash or collision.
- UAS are almost always considerably less expensive to operate and acquire than crewed aircraft platforms. This also makes them easier to replace.

- UAS data collection sensors, such as high-resolution cameras and thermal sensors, are considerably less expensive than their crewed counterparts. While UAS pilots do require training and practice, a UAS pilot can become safely operational during disaster considerably more quickly than a crewed aircraft pilot can.
- UAS can be launched from and land at a wider variety of locations than crewed aircraft.

Broadly, the drawbacks of small UAS include:

- Limited altitude under FAA rules, unless a waiver is secured.
- Much more limited ability compared to crewed aircraft to operate under adverse weather conditions like rain, snow, and windstorms.
- Limited ability to stay in the air without requiring a battery swap. Most small UAS have a maximum battery life of approximately 35 to 45 minutes.
- Extremely limited ability to physically transport objects and no ability to transport people or animals.
- Inability to carry very large sensors such as the large LiDAR units carried by crewed aircraft.

### T5.C What manned aircraft missions can UAS missions not yet replace?

UAS are not viable platforms for physically transporting people or animals. They are also not yet viable platforms for routinely delivering objects. No one the team spoke to reported regularly conducting deliveries with UAS platforms, although one interviewee did report using drones to drop incendiary balls for controlled burns. Fire suppression, another mission type that requires heavy lift capabilities, is unlikely to be replicated by UAS in the near future.

### T5.D What criteria is involved in the federal agencies responding to certain events? (State declaration of emergency?)

This FEMA document covers this in detail:
https://training.fema.gov/emiweb/downloads/is208sdmunit3.pdf

### T6.A What are the obstacles to UAS acceptance within the fire department and emergency services areas?

This section of the research was removed from this program. N/A

### T6.B What are the airspace challenges for use of UAS by the fire department and emergency services areas?

This section of the research was removed from this program. N/A

### T6.C What certifications and training should be required for fire department and emergency services areas to assure successful use of UAS in support of the emergency operations? What internal or external policies or processes are being utilized? What is in place to support UAS operations?

While the FAA's Part 107 license is required for disaster UAS pilots, it is not sufficient. Part 107 only represents very basic UAS knowledge and has no practical component.

Currently, there is no single, widely known, and widely used standard for disaster UAS pilot training or certification. During a disaster, organizations and individuals struggle to determine how much actual expertise and experience UAS users who wish to operate in the affected area have. Organizations sometimes are forced to spend time assessing the relative expertise of potential partners, as there is no single widely accepted, reliable credential for UAS disaster response knowledge.

The creation of such a program and/or credential would be a very valuable step towards ensuring that all UAS pilots in disaster are on the same page. This type of program was recommended by numerous interview respondents as an opportunity to involve their emergency operations and coordination.

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