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USING UNMANNED AERIAL SYSTEMS TO FACILITATE TRAFFIC INCIDENT MANAGEMENT

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16. Abstract

Incident management teams (IMTs) minimize crash impacts and create a safer highway network for people and communities. Research has shown that optimizing the IMT fleet has strong benefits to the roadway network, but future models indicate that increasing IMT presence may have diminishing returns after excessive roadway saturation. The Utah Department of Transportation (UDOT) would like to improve situational awareness in areas of poor or limited camera coverage, where situational awareness is typically poor. UDOT is considering the use of unmanned aerial systems (UAS) to provide live camera coverage of traffic conditions in these instances. This research report synthesizes practice from case studies within the United States to create a best practice report to guide future UAS implementation during IMT responses.

Ten state Departments of Transportation (DOTs) and one state Department of Public Safety were interviewed to create the State-of-the-Practice summary. Interviews focused on understanding UAS livestream implementations during incidents, although some discussions of developing technology are summarized. UAS livestreams are highly feasible and can provide substantial benefits to DOTs. However, there are concerns about technology and potential policy limitations regarding security and safety considerations.

Four key findings from the State of the Practice are summarized for UAS livestream integrations. These findings concern the use of UAS manufactured by DJI, tethered UAS, the role of satellite internet connections, and the various streaming solutions. Technology summary tables are provided for quick reference, with general recommendations for future implementations and for UDOT IMT response teams specifically.

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ARROW	Alaska Rural Remote Operations Work Plan
BVLOS	Beyond Visual Line of Sight
BYU	Brigham Young University
Caltrans	California Department of Transportation
CCP	Chinese Communist Party
CCTV	Closed Circuit Television
COA	Certificate of Authorization (also referred to as Certificate of Waiver)
DelDOT	Delaware Department of Transportation
DOT	Department of Transportation
DOT&PF	Department of Transportation and Public Facilities (Alaska)
DPS	Department of Public Safety
EDC	Every Day Counts program
ESRI	Environmental Systems Research Institute
ETT	Excess Travel Time
EUC	Excess User Cost
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FY	Fiscal Year
GPS	Global Positioning System(s)
HDMI	High-Definition Multimedia Interface
IMT	Incident Management Team(s)
IP	Internet Protocol
IT	Information Technology
ITE	Institute of Transportation Engineers
LAANC	Low-Altitude Authorization and Notification Capability
LiDAR	Light Detection and Ranging
MassDOT	Massachusetts Department of Transportation
MATSim	Multi-Agent Transportation Simulation
MDOT	Michigan Department of Transportation

NCDOT	North Carolina Department of Transportation
NDAA	National Defense Authorization Act
NSA	National Security Agency
ODOT	Ohio Department of Transportation
PennDOT	Pennsylvania Department of Transportation
PIN	Personal Identification Number
RCT	Roadway Clearance Time
RTMP	Real-Time Messaging Protocol
SMART	Strengthening Mobility and Advancing Revolutionizing Transportation
SOC	Statewide Operations Center
STIC	State Transportation and Innovation Council
TAC	Technical Advisory Committee
TIM	Traffic Incident Management
TOC	Traffic Operations Center
TxDOT	Texas Department of Transportation
UAF/ACUASI	University of Alaska Fairbanks' Alaska Center for UAS Integration
UAS	Unmanned Aerial System(s)
UAV	Unmanned Aerial Vehicle(s)
UDOT	Utah Department of Transportation
UHP	Utah Highway Patrol
URL	Uniform Resource Locator
U.S.	United States
USDOT	United States Department of Transportation
VDOT	Virginia Department of Transportation
VPN	Virtual Private Network

EXECUTIVE SUMMARY

Crashes and other atypical planned or unplanned events are increasingly common on Utah roadways. A complete image of the situation is beneficial to respond to these incidents effectively. In high-traffic areas, the Utah Department of Transportation (UDOT) has installed a robust system of traffic cameras to monitor roadway conditions and inform crash response. However, in less populated areas, situations when the camera is broken, or in locations of poor coverage, it is challenging to observe incidents and to inform emergency responses.

Unmanned aerial systems (UAS), are used by UDOT's Incident Management Teams (IMTs) to create digital 3D models of crashes or other incidents. Unmanned aerial vehicles (UAV) are the individual vehicles comprising UAS, while UAS also includes ground communications and connected systems. Other crews within UDOT also use UAS to create maps or perform bridge inspections. However, UDOT has a limited history of using UAS for livestreams. Faced with the plethora of potential solutions, a State-of-the-Practice summary was conducted to summarize how other Departments of Transportation (DOTs) are using UAS for livestreams.

Representatives from 10 DOTs and a state Department of Public Safety were interviewed, and their practices were consolidated into a State-of-the-Practice summary. Livestreams from UAS are a developing technology, and DOTs use various techniques to share UAS video data remotely. DOTs use tethered and untethered UAS platforms to livestream and/or record aerial imagery. These data are transmitted over cellular or satellite internet, with limited integration of secured cellular internet. To maintain secure streaming services, third-party solutions, including Airdata UAV and DroneSense, are used instead of conference calls or native UAS streaming apps.

From the State of the Practice, several key considerations were identified for UAS livestreams. Due to national security concerns, UAS manufactured by DJI are facing a potential ban in the United States. Many DOTs and other government entities are purchasing alternate UAS to meet this concern. Additionally, tethered UAS are a powerful tool for extended livestreams but are less useful in shorter incidents. When streaming UAS data live, many DOTs use cellular internet connections. In rural areas, satellite internet is frequently used, and some

DOTs have even pursued internal solutions, such as connecting UAS to camera networks. When beginning UAS livestream programs, many DOTs rely on conference call software or internal UAV streaming services. However, these solutions have limitations that can be mitigated with third-party software that provides secure streaming and/or UAV fleet management services.

This report provides several recommendations to UDOT for integrating UAS into traffic incident management by IMT response crews. It is recommended that UDOT IMT transition from UAS manufactured by DJI to an alternate UAS and acquire a tethered UAS with a satellite internet connection for significant incidents. Additionally, internal discussions between IMTs and the UDOT Traffic Management Division are required to select appropriate long-term streaming solutions.

By creating a State-of-the-Practice summary, implemented DOT practices highlight key considerations for future UAS livestreams. With these in mind, recommendations were provided to UDOT. The findings from this report could also assist other groups looking to integrate UAS livestreams into their operations when considering UAS legislation and available technology.

1.0 INTRODUCTION

1.1 Problem Statement

Incident Management Teams (IMTs) are heavily used on Utah Department of Transportation (UDOT) freeways to manage crashes and other incidents as part of UDOT's Traffic Incident Management (TIM) program. A vital element of the IMT response is gathering information from closed circuit television (CCTV) through UDOT's network of cameras. However, providing insight into traffic conditions in rural areas with limited CCTV data coverage or in urban areas with gaps in CCTV coverage can be challenging.

This research investigates using unmanned aerial systems (UAS) to explore practical solutions to providing video feed coverage during IMT response, specifically by transmitting live video feeds from unmanned aerial vehicles (UAV) to UDOT's Traffic Operations Center (TOC). Areas without CCTV coverage limit the ability of the TOC to provide informed traffic management instruction and situational response specifics. Instead, IMTs often act based on limited information from first responders and the public. UDOT hopes to provide better instruction to first responders and traffic operators in managing and rerouting traffic flows by enabling an instantaneous connection between the TOC and UAV coverage at incident sites. The following report details the creation of a State-of-the-Practice report and its findings on using UAV livestream during IMT response.

1.2 Objectives

This research has two main objectives. First, to synthesize practices from case studies of using UAV livestream coverage during IMT response into a State-of-the-Practice Summary. Second, to understand UDOT's IMT UAS capabilities and provide recommendations for implementation.

1.3 Scope

The Technical Advisory Committee (TAC) approved the following tasks to complete the research objectives. Task 1 instigated the research study with a meeting between the TAC and researchers to clarify the scope of the research. Task 2 synthesized previous research on UAS and IMTs and identified vital attributes that facilitate collaboration. The research team also reviewed prior research on the UDOT IMT program and resources provided by the Federal Highway Administration (FHWA). Task 3 developed a State of the Practice by synthesizing projects and examples from companies, state Departments of Transportation (DOTs), agencies, and vendors implementing UAV livestream transmission. Task 4 summarized these results and compared them with IMT UAS capabilities at UDOT. Specific resource limitations were reviewed and summarized. Task 5 developed conclusions and recommendations for UDOT based on the findings from the State of the Practice while developing a pilot program implementation of UAS livestream transmission during incident management scenarios.

1.4 Outline of Report

The outline of the report is as follows:

1. Introduction
2. Literature Review
3. State of the Practice
4. Synthesis of Practice
5. Conclusions
6. Recommendations and Implementation

Chapter 2 provides a comprehensive literature review concerning UAS, IMTs, and their interactions. Chapter 3 explains the relevant case studies from the State of the Practice. Chapter 4 summarizes these case studies and synthesizes the best practices by highlighting key considerations for UAS livestream implementation. Chapter 5 outlines the various hardware and software solutions used by groups in the State of the Practice, their relative strengths and benefits, and some of the limitations of this study. Finally, Chapter 6 provides recommendations to UDOT on methods to implement this technology during incident response or similar events.

2.0 LITERATURE REVIEW

2.1 Overview

This chapter provides the background information necessary to complete the aims of the research through a literature review. Journal articles, webinars, websites, reports, and other media forms were collected from various databases and online resources. The completion of the literature review provided a foundation of information and a search for relevant studies that informed the development of this research. Compiling this literature review has helped guide the research team through the method development and subsequent analysis.

The literature review has three parts. First, it explores the history and practical applications of UAS. Then, a brief history of federal UAS regulations is summarized, highlighting critical considerations for UAS deployment. Finally, it describes the implementation of IMTs, integrations of UAS with IMT, and their impact.

2.2 Unmanned Aerial Systems

Drones, or UAS, have a long and rich history in the United States (U.S.) and worldwide. This section will describe the history of UAS, particularly as it relates to the U.S., followed by a description of the abilities of UAS to collect photometric data, and finally, data quality factors that contribute to UAS effectiveness.

2.2.1 Brief History of Unmanned Aerial Systems

Apart from unmanned hot air balloons used by researchers and weather forecasters for atmospheric data collection, the defense industry first developed UAS for military-related purposes. Radio-controlled UAVs were developed during World War I as missiles or torpedoes for air-to-ground fighting. However, the conflict ended before comprehensive implementation of such devices on the battlefield was possible. During World War II, combatants began using this technology, expanding their use to anti-aircraft target practice. Military use of UAS technology further has expanded in use during war-time conflicts, including during the “War on Terror” and the Ukrainian and Israeli/Palestinian conflicts. In these conflicts, UAS use has varied from being used as or armed with weapons, or for military surveillance and data collection (Custers, 2016).

Aircraft without an onboard pilot and controlled remotely through a communication center or handheld controller are commonly known as “drones.” The term UAV focuses on the drone specifically, while UAS refers to the device and the connected ground station. Other phrases, including Remotely Piloted Aircraft Systems, Unmanned Combat Aerial Vehicles, Micro Aerial Vehicle, and micro-copters, have also been used. UDOT documentation primarily refers to drones and connected systems (including users) as UAS. Thus, “UAS” will be the primary term used in this report for this type of technology. When addressing a singular drone, or the drone’s payload or flight capabilities, the term “UAV” may also be used. “Drone” may also be used in the report in various instances.

Once UAS technology was made public, it was quickly developed for civilian purposes (Vergouw et al., 2016). Commercial and private UAS applications have since become widely available and integrated by private vendors, hobbyists, and consulting firms for various purposes. Relevant research applications have primarily focused on the ability of UAVs to collect photographs and other photometric data from higher elevations. Applications have expanded to use machine learning algorithms to improve route planning and data processing for information collection.

Due to Federal Aviation Administration (FAA) line-of-sight requirements for UAVs and the needs of UDOT, machine learning applications will not be discussed in this report. Many of the referenced sources focused their research on highly technical optimization problems, and the findings will be simplified for the literature review.

2.2.2 Photometric Data Collection Capabilities

COVID-19 offered a variety of unique situations, including emptying college campuses across the world. In Provo, Utah, researchers at Brigham Young University (BYU) took the opportunity to collect UAV imagery of the entire campus. These images were compiled into a single 3D model of the BYU campus, capturing a historical record of the campus and providing information for planning new developments, as well as documenting methodologies and best practices for 3D model creation from UAS images (Berrett et al., 2021). This study illustrates the abilities of UAS to create synthesized images from separate photos post-flight. UDOT IMTs are also using this technology, often referred to as photogrammetry, for crash investigation and reconstruction purposes, winning the UDOT 2022 Innovation Award for significantly reducing time at crash sites (UDOT, 2022).

Figure 2.1 illustrates the process of capturing images when creating a 3D model. After the extent and detail necessary for a 3D model recreation of an object are determined, a UAV flies around the object, capturing images from different angles and heights. Berrett et al. (2021) experimented with optimizing the images taken to reduce storage requirements and processing time. A software compares the images by finding "tie points" or identifiable features that are the same in different photos. Using the image metadata (XYZ point coordinates, camera angle, etc.) computer programs use these tie points to create a point cloud. Rendering from that point cloud creates a 3D model, digital surfaces, ortho-mosaic images, and other outputs.

Figure 2.1: 3D Model Creation from Multiple Images (Wright, 2022).

With the development of Light Detection and Ranging (LiDAR), multispectral, and thermal cameras, UAVs have collected alternative high-resolution imagery for various applications. Stevens and Blackstock (2017) believed that using LiDAR data in crash reconstruction could create better models to provide a record of fatal crash scenes. Thermal data could be used to track vehicle movements and other heat signatures, specifically looking at roadway facilities for signs of deterioration or failure (Zhao et al., 2023b). UDOT IMTs use thermal technology on UAVs to find weak points in mountain snowbanks, advise avalanche crews, and close roadways (Utah Public Radio, 2019).

2.2.3 Data Quality Factors in Effectiveness of Unmanned Aerial Systems

Using UAVs at higher elevations and faster speeds can reduce computed image resolution and potentially UAS effectiveness. Computed ortho-image resolution is often correlated with UAV height, image overlap, and the use of computer algorithms.

The higher the elevation or farther away a photograph is taken, the more area is visible. With the same number of pixels being used for more extensive areas, the resolution of the image decreases. This issue may be minimized with high-resolution cameras on many UAVs, but this interaction is a crucial element of photogrammetry. With a standard commercially available quadcopter UAV and the built-in UAS camera, Seifert et al. (2019) found a non-linear relationship between UAV elevation, image overlap, and reconstructed image resolution. UAVs were flown over various flight paths alternating in elevation, image overlap, and UAV speed. The images were then reconstituted into a point cloud and a photo-rectified image using photogrammetry or using individual images to create a composite image.

When using UAS to collect data for a land survey, or to create an ortho-mosaic photo, UAVs are flown in a grid-like pattern, as shown in Figure 2.2. Each photo taken along the flight path is designed to have a certain amount of side and frontal overlap. This overlap allows programs to find common points between pictures to use as tie points when combining images.

Higher quality orthophotos are possible when side and frontal overlap is increased. However, to increase overlap, the UAV flight path needs to be more compact, increasing flight time to cover the same area. Due to UAV quality, resolution at heights greater than 50 m (164 feet) remained similar, with an optimal flight elevation of 10-30 meters (33-98 feet) if the same number of images is maintained (Seifert et al., 2019). As elevation increases, processing time and resolution decrease, but increased forward and side image overlap increases processing time and final image resolution.

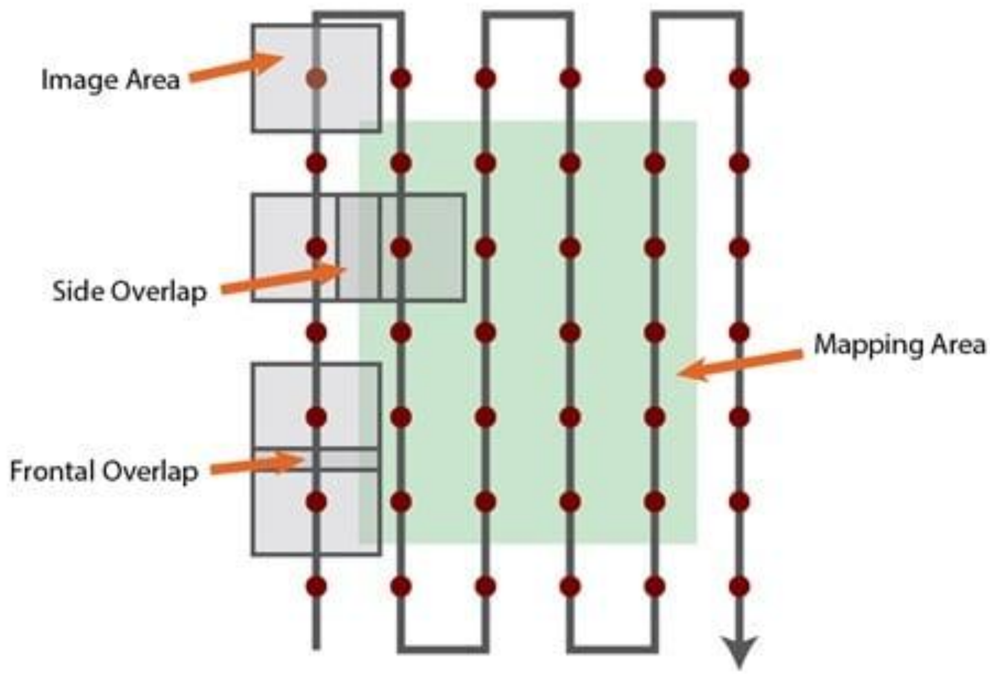


Figure 2.2: Illustration of Frontal and Side Image Overlap (Dascalu, 2022).

When taking images of roadways, the contrast between roadway elements is often distinct, but increasing elevation, topography, and landscapes can degrade image clarity and resolution, rendering features in the image indistinguishable to the human eye. Machine learning can be used to identify traffic characteristics from these images, as shown extensively by Gupta and Verma (2022). Using aerial imaging, the researchers detected crashes using various surveillance algorithms. Their models show varying levels of success but illustrate an exciting development that will revolutionize how traffic data are collected. The same data used to identify crashes can also generate traffic counts, origin-destination data, speed data, and delay estimates. For example, Elistar uses UAS to collect traffic data statistics (Elistar, 2023). However, to preserve privacy, the recommended practice is to track vehicles without collecting identifiable data, and when private data are gathered, footage should be deleted soon after processing (Utah Public Radio, 2019).

As Zhao et al. (2023a) illustrated, satellite imagery could also collect traffic and crash verification data. However, in general practice, DOTs generally do not own satellites and purchasing this data at ultra-high resolution and in real time may be cost prohibitive, except in collaboration with federal and private organizations. A more readily accessible data source from satellites could include global positioning system (GPS) data. GPS transmitters are found in most modern devices, including cellular devices and vehicles, and can track vehicle movements. As vehicle GPS data can be purchased, it was posed that the two datasets could be combined.

In one study, researchers calculated average vehicle speeds and flow rates by collecting 7 percent of all vehicle user data (Kristiansen et al., 2003). This system worked best in areas with minimal infrastructure interactions (buildings, bridges, etc.) to avoid blocking GPS signals. Sheehan et al. (2023) conducted a similar study in an urban area and found that GPS technology increased traffic data collection accuracy. However, limitations exist in areas with lower traffic counts or mountainous regions where commercial GPS receivers cannot consistently transmit signals. Vohra et al. (2022) showed that more accurate counts may be possible when GPS data are used with UAS to verify and corroborate the data.

Another critical factor in UAS effectiveness is the cost efficiency of image resolution. Muchiri and Kimathi (2016) found that data collected from UAS multispectral and thermal imaging was comparable to agricultural crop growth data collected from a manned aircraft, although at a much lower cost. While these flights needed lower altitudes to maintain data resolution, traffic data does not require as high a resolution as crop data. Similar principles may apply to other transportation collection methods. For example, higher resolutions may be necessary to measure pavement or material fatigue, with recommendations ranging from 5 meters (16 feet) (Zhao et al., 2023b) to upwards of 100 meters (328 feet) (Ibrahim et al., 2023) depending on the type and quality of hardware used and the use of the data.

More research must be conducted to explore optimal heights and image overlaps for UAS imagery collection in traffic applications. UAS implementations are growing yearly with new and practical implementations that reduce user risk and increase data accuracy. Many of the applications related to TIM have been developed in other fields but require additional experimentation to fully adapt UAS practices to TIM use, particularly with driver safety concerns and the feasibility of video livestream transmission. Depending on the need of the application, operators may collect photos or video data. However, the general principles may be similar.

2.3 Federal Guidelines for Operations of Unmanned Aerial Systems

Beginning in the early 21st century, the legal landscape surrounding UAS and their use by various entities has gradually developed. This section will summarize federal (U.S.) regulations and highlight potential developments that will play significant roles when integrating UAS livestreams with traffic incidents. Potential bans on UAS providers will be discussed, followed by a review of privacy concerns relating to UAS.

2.3.1 Early Federal Regulations and Introduction of Part 107

Testing of UAS in the U.S. began in the 20th century, but the first commercially authorized UAV flight was not until the 21st century. In 2005, General Atomics Altair developed a version of their Predator drone for research purposes with the National Aeronautics and Space Administration (FAA, 2022). Before this point, little consensus had been reached on what UAS legislation should look like; instead, multiple federal agencies had developed internal directives without a clear, unified, overarching direction. Congress directed the FAA and Department of Defense to form an executive committee to consolidate visions of UAS integration into the national airspace. The Committee was established in 2008 and, in 2014, resulted in the selection of six test sites to research the safe integration of UAS into national airspace. Through these efforts, the FAA was recognized as the main authorizing body for UAS regulations, with assistance from other federal agencies.

The FAA released a restricted authorization path in 2013 for commercial UAS operators, which provided a limited avenue for UAS flights (FAA, 2022). The first quadcopter received FAA Certification for public infrastructure inspections in 2014, and the issuance of an emergency Certificate of Authorization (COA) (also referred to as a Certificate of Waiver) became accepted practice, such as when delivering vital assistance in the 2013 Yosemite Wildfire. Most FAA UAS regulations concern commercial pilots, including first responders and public agency pilots. Hobby UAS pilots have been more restricted in where they can and cannot fly, but registration is simpler. The FAA developed commercial pilot regulations to allow for more complex flights with heavier UAVs to collect specialized data and to allow for more stringent safety regulations and accountability. The general policy under COA has been that the pilots should pass a safety test and fly within approved airspace. These pilots are not allowed to fly over people and face other restrictions unless granted waivers from the FAA.

In 2015, FAA guidance was released on the use of and response to UAS by first responders (FAA, 2022). A UAV crash on the White House front lawn highlighted this need, as radar systems were not adequately developed for small UAVs and posed a significant security risk. No-fly zones were also declared for the greater Washington metropolitan area and other locations during dignitary visits, such as the Papal visit later that year. First responders and security professionals have developed radar jammers and other techniques to remove the UAS from restricted airspace. Officers are also trained in methods to identify the pilots of unapproved UAS for seizure of the UAS, or to inform the user of restricted airspace. The FAA categorizes UAS as aircraft, and attacks on UAS carry similar weight to attacks on crewed aircraft.

By early 2016, a COA was made mandatory for commercial UAS flights, and efforts to simplify the process were being developed. To acquire a COA, an organization fills out a detailed application describing how UAS flights would be monitored, how pilots would be trained, and how the organization would mitigate risks. The process is very thorough and often takes several years with varying levels of success. In August 2016, Part 107 was implemented (CFR, 2025), opening the door for widespread commercial UAS use, with 80,000 registrants in the first year (FAA, 2022).

Through Part 107, a COA was no longer needed for commercial flights. Instead, operators could acquire a personal UAS operator’s license, allowing individuals to fly commercially with safety and airspace restrictions. Some restrictions included the ability to fly over people and traffic, flights at night, and flights from a moving vehicle. If an operator believes that an exception is warranted, waivers are requested from the FAA. In October of 2017, the first waiver to operate over people was authorized, subsequently followed by waivers for night flights, flights from a moving vehicle, flying over vehicles, and other exceptions (FAA, 2022).

UAVs between 0.55 and 55 pounds (or large UAV) can be flown commercially only by Part 107 licensed operators or through a COA. Hobbyists can fly UAVs weighing up to 55 pounds, provided they take a training program and abide by federal and local restrictions. UAVs lighter than 0.55 pounds are called “small UAVs” in this report. UAVs heavier than 55 pounds are not discussed at length in the report unless specified. The FAA has categorized national airspace under various categorizations, ranging from A (highly restricted) to G (very few restrictions). These airspace categorizations and limitations are summarized in Figure 2.3. Airports, government buildings, and other private industries can apply for increased flight restrictions, creating a complicated network of airspace restrictions (FAA, 2024).

Figure 2.3: FAA Airspace Classifications (FAA, 2024).

Specific events can also limit surrounding airspace, including dignitary visits, entertainment events, and large gatherings. Following several airspace violations, primarily due to the pilot being uninformed, the B4UFLY app was developed to summarize flight restrictions, and UAV registration was created for small UAVs. In 2020, the FAA finalized the Remote ID rule, mandating that all large UAS should constantly broadcast their position and other flight-sensitive data to the FAA. Under this regulation, large UAVs (over 0.55 pounds) must be registered with the FAA under the RemoteID, requiring the UAV to constantly transmit flight and positioning data.

One of the FAA's roles is to oversee aircraft to prevent airborne collisions. The integration of UAS in airspace management (or UAS Traffic Management) is still being developed, but the first formal steps allowing for waivers to fly near airports occurred in 2017.

UAS air traffic control permits for flights in airport airspace (technically named the Low Altitude Authorization and Notification Capability or LAANC) were developed in 2017 following a collision between a small UAS and an Army Helicopter. Airports have different airspace designations, and UAS flights are usually prohibited. However, with these waivers and local coordination with air control, pilots can fly within certain parts of that airspace.

At the time of writing this report, various developing legislations will influence UAS use practices. Table 2.1 illustrates the development of legislation and other key factors in UAS deployment through September 2024. Key elements of the legislation are bolded and underlined for emphasis. When considering these and other developing guidelines, including potential UAS bans and the removal of flight practice restrictions, policy administrators and UAS operators should be careful to understand the status of legislation.

The Countering Chinese Communist Party (CCP) Drones Act (Rep. Stefanik, 2022), as presented in the U.S. House of Representatives, would ban all imports of UAS manufactured by DJI and give the FAA authority to revoke flight permissions for DJI UAS. To assist in fleet replacement, the Drone for First Responders Act (Rep. Stefanik, 2024) was introduced to implement a tariff on DJI sales during the intermediary time before complete banning while using tariff revenue to provide grants to first responders to replace DJI UAS. These proposed legislations were presented in the U.S. House of Representatives, and an alternate bill in the U.S. Senate (Sen. Scott, 2024) combines these two bills. A key difference, however, is that a tariff on DJI UAS would not be implemented while still providing matching grants to first responders.

In 2018, the FAA Authorization (Rep. Graves. 2024) opened many avenues for UAS implementation, including tethered systems, for public drone operators. Under these regulations, a group under a public drone operators' designation did not need a Part 107 license to operate an actively tethered UAS. In 2024, the ability to use tethered UAS without a Part 107 license was extended to public safety organizations, including volunteer fire response, police departments, and other safety response organizations. Although one of the primary purposes of a DOT is to improve the safety of travelers, acquiring this designation for traffic operations engineers or response teams is uncertain. If applicable, a DOT could bypass UAS flight restrictions for tethered UAS flights, although tethered UAS costs more than untethered UAS.

Table 2.1: Developing and Implemented UAS Legislation

Name	Purpose	Status
Countering CCP Drones Act (Rep. Stefanik, 2022)	Adds drones manufactured by DJI to the FAA Unacceptable Risk List, effectively banning all imports, and **could result in the revoking of all DJI FAA Authorizations.**	Introduced Feb. 3, 2022 (part of NDAA for FY25) Passed House Sept 9, 2024
Drones for First Responders Act (Rep. Stefanik, 2024)	Imposes a **tariff on Chinese-produced drones** and provides **grants to first responders** to buy approved drones. After 2030, all Chinese drones and parts would be banned from U.S. entry and distribution.	Introduced May 15, 2024
Countering CCP Drones and Supporting Drones for Law Enforcement Act (Sen. Scott, 2024)	Combines the Countering CCP Drones Act and the Drones for First Responders Act but recommends no tariffs while providing matching grants to first responders.	Proposed in Senate July 30, 2024
2024 FAA Reauthorization (Rep. Grave,s 2024)	Allows public safety organizations to fly actively tethered UAS **without a Part 107 license** and COA in most airspaces.	Ratified May 16, 2024
U.S. 4th Amendment: Right to Privacy (U.S. Constitution, 1791)	Protects citizens against unwarranted searches and surveillance. How this applies to drones is being debated, but most DOTs and police forces must delete data to be compliant.	Ratified Dec. 15, 1791
Various Local and State Laws	Regional governments can govern drones within their jurisdiction. The extent of legislation and dates varies among governing bodies.	Constantly in flux

In December 2016, the first Beyond Visual Line-of-Sight (BVLOS) flight was authorized at a test site. Line-of-sight restrictions maintain that UAS must be flown within the visual line of sight of the pilot, which limits flights to within half a mile of the operator. Such distances can be prohibitive to large-scale operations, particularly with air transportation or package delivery.

Since 2016, the FAA has released several waivers for BVLOS, and as mandated by Congress in the 2024 FAA Reauthorization Act, it will establish updated rules, sometimes referred to as Part 108, by January 2026. These guidelines are expected to enlarge UAS operations in the U.S. and open the door for air taxis and full UAS integration in U.S. airspace.

2.3.2 Proposed and Enacted Bans of Unmanned Aerial Systems

Throughout legislative history, a handful of UAS manufacturers have been banned from operating due to failures to comply with operational guidelines. However, very few have been universally and irrevocably banned until 2020. In the National Defense Authorization Act (NDAA) for FY 2020, Congress required the Defense Innovation Unit of the Department of Defense to create the “Blue UAS” list, sometimes referred to as the NDAA Blue list, or NDAA approved UAS. The purpose of this list is to identify UAS and camera platforms with minimal risk to national security. At the time of publication, there were over 14 UAS companies and 20 UAVs on the list (Defense Innovation Unit, 2024).

In 2022, the Department of Defense marked DJI or Shenzhen DJI Sciences and Technologies Limited products as a national security risk, effectively banning them from all federal use, even for use by contractors. Individual states and agencies have also implemented similar bans, and the U.S. Congress is considering a national commercial-level ban, limiting consumers from purchasing and using DJI drones in U.S. airspace. In 2024, Autel Robotics has also appeared on some lists for potential bans due to alleged security concerns with the company having Chinese interests.

An effort to pass a universal DJI ban was proposed in the House of Representatives in their version of the NDAA for Fiscal Year 2025 as the Countering CCP Drones Act (Rep. Stefanik, 2022). An alternate version of this bill, combined with legislation introduced in the House, the Drones for First Responders Act, was proposed in the Senate for inclusion in the NDAA for FY25 to ban DJI drones while providing matching grant funds for first responders to acquire approved UAS (Sen. Scott, 2024). Neither bill was included in the final ratified NDAA for FY 2025. Instead, a provision was added granting DJI and Autel manufacturers one year to pass a risk assessment proving their safety (Grigonis, 2024).

2.3.3 Privacy and Fourth Amendment Concerns

When personal data such as photos or recordings are collected, privacy regulations from the U.S. Fourth Amendment are critically important and regularly debated. UAVs often collect sensitive personal data while capturing traffic flows and scene preservation images. Issues sometimes arise when these data are shared with first responders for legal or safety considerations. This section describes some of the legal cases surrounding the Fourth Amendment regarding data collected from aerial surveillance, including from UAS.

The Fourth Amendment, which safeguards U.S. citizens from unreasonable searches and seizures by U.S. national, state, and local governments, faces evolving challenges in the context of UAS technology. The Supreme Court has traditionally held that aerial observations from public airspace do not constitute a "search" under the Fourth Amendment, provided there is no reasonable expectation of privacy. In *California v. Ciraolo* (U.S. Supreme Court, 1986) and *Florida v. Riley* (U.S. Supreme Court, 1989), the Court ruled that observations made from standard aircraft flying in public airspace did not breach privacy because the technology was not considered novel, and the observed areas were also visible to the public.

UAS technology introduces complexities that challenge these precedents. UAS offers capabilities such as hovering at low altitudes and capturing detailed images, which were not possible with traditional aircraft. In March 2021, the Michigan Court of Appeals found that using a UAV to survey a citizen's backyard without a warrant violated the Fourth Amendment, distinguishing it from *Florida v. Riley* by emphasizing the more intrusive nature of UAS. The question in *Long Lake Twp v. Maxon* (Michigan Supreme Court, 2024) was whether a township could use a UAV to collect data to enforce zoning codes, as the defendants in question were suspected of turning their backyard into a salvage yard, contrary to local zoning regulations. However, in May 2024, the State of Michigan Supreme Court disagreed that the protections against UAV surveillance under the Fourth Amendment apply to civil cases and remanded the case to the trial court for further proceedings.

Several cases highlight these evolving concerns. For example, in *Leaders of a Beautiful Struggle v. Baltimore Police Department* (U.S. Fourth Circuit Court, 2021), the Fourth Circuit Court ruled against a wide-area aerial surveillance program utilizing drones, determining it constituted a novel and persistent surveillance form that breached reasonable privacy expectations. This and other legal challenges have underscored the invasive potential of UAS technology in gathering detailed, continuous data, reinforcing the need for warrant requirements.

These cases illustrate the ongoing legal tension between the benefits of UAS surveillance for emergency management and the constitutional protections afforded by the Fourth Amendment. As UAS technology advances, courts will likely continue to refine the boundaries of privacy expectations in aerial surveillance. Thus, decisions will impact how and where DOTs can collect data, what that data can be used for, how long it can be stored, and with whom it can be shared.

2.4 Incident Management Teams

In 2009, the FHWA publicly endorsed implementing TIM programs and detailed performance measures for their evaluation (Owens et al., 2009). These programs include collaboration between DOT officials, state highway police, roadway cleanup crews, and IMTs. This greater collaboration aims to improve user safety, decrease congestion, reduce emissions, prepare for large-scale disasters, and improve public satisfaction. This section will discuss the implementation of IMT programs, explore steps taken to strengthen IMT effectiveness, and conclude with a brief discussion of the implementation of UAS during IMT response.

2.4.1 Implementation of Incident Management Teams

IMTs have been shown to be highly effective when running 24/7 for instant response to any scenario (Schultz et al., 2021). Numerous variables are used to measure IMT effectiveness, including response time, incident clearance time, roadway clearance time (RCT), and the overall impacts of IMT programs through road user costs. These measures include excess travel time (ETT) and excess user cost (EUC), which estimate the impacts of a crash on road users as a function of the total incident and roadway clearance time, and overall network delay.

ETT is calculated as the aggregate time road users take to travel a road segment during the incident compared to the same road segment without an incident. EUC is a function of the ETT and the estimated economic cost of time. Studies across the country have shown the critical nature of effective IMTs by using these principles. For example, a study in Georgia concluded that their IMT program saved motorists an annual 7.2 million vehicle hours, the equivalent of $300 million, with a cost-benefit implementation ratio of 1:4 (Guin et al., 2007).

These measures of effectiveness are designed to minimize the impact on the driver and provide for safer roadway conditions. As ETT increases, driving stress and frustration are likely to rise, sometimes leading to more radical driver behavior. A Federal Bureau of Investigation report highlighted the catastrophic nature of this risk. In 2021, a total of 52 police officers died in traffic-related crashes in the U.S., including 20 fatalities while acting in the line of duty outside of their vehicles (Perine and Arnold, 2022). Construction and emergency response personnel are already at risk when responding to crashes, and minimizing this hazard is essential.

Drivers failing to recognize and react appropriately to traffic queues can cause secondary crashes. Due to unreliable data collection, estimating the percentage of crashes that have a secondary crash is challenging. Estimates say that secondary crashes account for around 20 percent of all incidents and 18 percent of road fatalities (Zhang et al., 2022). Secondary crashes may increase the demand for incident response personnel more than the demands of the first crashes, further increasing ETT and potentially causing additional crashes. However, IMTs can decrease the risk of first responder traffic strikes and secondary crashes by decreasing ETT. One study estimated that for every minute a queue persists, the likelihood of a secondary crash increases by 1.2 percent (Yang et al., 2014). The study compared its findings to studies from over 20 years ago, which estimated this effect between 1.8 and 3.2 percent. This decrease may also correspond to the introduction of automatic emergency braking technology.

Sequential studies evaluated the role that IMTs play on UDOT roadways by calculating ETT and other measures of effectiveness over time and with growth in the IMT force. These studies used ETT, EUC, and other UDOT-specific variables to measure IMT effectiveness. In 2018, the researchers found that the IMT response influenced the EUC significantly when coupled with the Utah Highway Patrol (UHP) response during crashes (Schultz et al., 2019).

Following this study, UDOT effectively doubled the size of its IMT force. A second study compared 2018 data to 2020 data (Schultz et al., 2021) and found that the increase in the IMT supply saved drivers around 33,000 hours in ETT, equating to around $53.3 million in

EUC. Due to unforeseen response complications and significant traffic volume differences during the COVID-19 pandemic, a follow-up study in 2023 reproduced the earlier research by comparing 2018 data to 2022 data. Researchers found that ETT was significantly reduced in 2022 compared to 2018, with the median ETT per crash decreasing by 40 percent, showing that IMTs continue to benefit roadway users (Schultz et al., 2023). To further improve IMT success, follow-up studies investigating optimal IMT placement and quantity were recommended.

2.4.2 Improving Response Effectiveness of Incident Management Teams

To evaluate and predict the benefits of IMTs under various planning scenarios in Utah, a study was conducted using Multi-Agent Transportation Simulation (MATSim) modeling software. Within the model, different scenarios were evaluated to estimate the effectiveness of multiple sizes of the IMT fleet related to where individual IMTs were staged and the number of crashes occurring. When the study compared delay from models with no IMTs to models with 2022 IMT levels, implementing IMTs decreased delay by 18.2 percent. However, when IMT levels were further increased by 50 percent, the delay decreased to 22.9 percent of the delay in the no-IMT models (Macfarlane et al., 2024). As the 50 percent increase in IMT volume was correlated with a proportionally small actionable decrease in delay (approximately a 20 percent decrease), it was suggested that having more IMTs may not necessarily lead to a reduction in highway delays if not appropriately staged or if the network is oversaturated with IMTs. This supports the argument that the quality of IMTs may have a more significant impact than the quantity of IMTs. However, this was the first iteration of such a novel idea, and the MATSim model required additional calibration to avoid misestimating the distribution of IMT response time and oversimplifying crash complexity and driver response.

To coordinate the deployment of IMTs, TOCs adjust local traffic cameras to provide optimal coverage of the incident site and surrounding traffic. Based on what is visible, instructions are supplied to IMTs to alter lane closures or improve crash response. UDOT has an extensive network of traffic cameras covering all major highways and can adjust camera angles and magnification instantaneously. However, in rural areas with limited cellular and camera coverage, TOCs have limited situational awareness. In these scenarios, using UAS to provide real-time video feed of traffic conditions is of interest to DOTs. This same technology could also be used to improve response to significant disasters, or special events (Jodoin et al., 2021).

Studies on the effectiveness of UAV footage supplementing CCTV systems illustrate how UAVs can overcome literal blind spots in camera coverage. CCTVs are typically placed one-half to one mile apart and only face one direction at a time. This single view limits the ability of the CCTV system to aid the TOC fully in IMT response. A 2021 study in Stellenbosch, South Africa, sought to understand the benefits of using UAVs in rural communities. While CCTV cameras were cost-effective on major arterials, the research determined it would not be cost-effective to have dense CCTV camera coverage in rural communities. The study concluded that a UAV with a range of 7 km (4.3 miles) would be as effective as about 15 CCTV cameras, costing much less when considering the materials needed for CCTV installation, mainly to purchase the galvanized steel poles and the cameras. In a case study to evaluate UAS performance, researchers found that the versatility of UAS provided more optimal camera angles and positioning. The researchers used the UAV to capture imagery more specific to the incident scene (Ebrahim et al., 2021).

2.4.3 Integration of Unmanned Aerial Systems with Traffic Incident Management

On their own, UAS and IMTs are separate ideas with minimal natural overlap. However, with the versatility of UAS, many industries can find applications for this technology. Incident management is no stranger to this, and agencies nationwide have begun integrating UAS into their TIM practices. This involves applications of UAS photography capabilities, creating orthographic images, 3D models, or livestreams. However, because TIM programs are closely intertwined with emergency response, these programs have unique considerations and requirements for UAS that may not be relevant to other implementations. When improperly used, UAVs can damage private property and risk personal safety. The misuse of DOT UAS in this way could cause significant harm to roadway users and the reputation of the DOT.

Data security must be considered when implementing UAS into TIM, specifically when connecting UAS with broadband streaming capabilities. Deebak and Al-Turjman (2020) showed that UAS data are prone to cyber-attacks when transmitted virtually. Still, security measures can be put in place to protect the data without hindering instantaneous data transfer. Due to the potential threats of unauthorized use, it is recommended to guard remote access to in-flight UAVs for safety and security purposes.

The FAA places various national restrictions on the use of UAVs, including limitations on weights, licenses, line-of-sight restrictions, no-fly zones, and UAV tracking. Additionally, local (city, town, state) jurisdictions may place other constraints to provide greater safety accommodations and prevent Fourth Amendment privacy violations. However, several studies have shown that UAS can still provide data to a TOC, even with all these limitations. For example, Stevens and Blackstock (2017) demonstrated that UAS could collect real-time video and sensor data to measure queues, the state of alternate routes, and map scenes, all while flying safely near live traffic and abiding by FAA requirements. A further exploration of these guidelines was presented in Section 2.3.

One challenge when implementing UAS into TIM is providing video feeds for the duration of the incident. Most small commercially flown UAVs only have a battery life between 30 minutes and 1 hour, depending on the make, model, and payload. One way to bypass this limitation is to use a “tethered” UAV connected to a ground unit through a cable, providing power and data transfer connections. A modification to this technology is to install a “drone in a box” within the right-of-way of a roadway, where a container is permanently installed with the capability of remote or in-person deployment of a tethered or untethered UAV without needing to transport one to the site. Additionally, implementing tethered UAVs enables simpler deployment or instantaneous collection of necessary information. Alden et al. (2022) conducted a state-of-the practice study on implementing UAS during normal traffic operations and showcased the technology through a case study using a tethered UAV. The researchers did not send the data elsewhere but instead viewed it live, in person from the tablet used to control the UAV to determine the effectiveness of the technology. By deploying the tethered UAS, the research team could visually determine queue lengths, see a crash and its impacts, verify secondary crashes, and utilize other traffic data collection possibilities, including traffic counts, origin-destination data, or speed measurements (Alden et al., 2022).

Some TIM programs have also considered the possibility of UAS communicating not only with the TOC but also with vehicles and infrastructure. In some cases, UAS are used to collect and transmit probe data to a central receiving station (Zhang et al., 2020). Using machine-learning capabilities, livestreams from UAS could also be used to find and confirm crashes quickly. Many of these implementations are still largely theoretical but offer exciting opportunities for future UAS implementation for traffic data collection and connected roadways (Pádua et al., 2020). Nawaz et al. (2020) experimented with the idea that UAVs could communicate with each other while in flight to accomplish military and civilian missions, including human rescue, environmental monitoring, and surveillance.

At higher elevations, UAVs traverse greater distances and thus could verify crashes quickly with FAA-granted exceptions. However, there would be severe limitations during nighttime conditions, in areas with vertical obstructions, and other situations requiring FAA approval. Prompt crash verifications could also require using fixed-wing UAVs or UAVs with longer battery life (Pádua et al., 2020). Innovations within the private industry are laying the groundwork for UAVs to fly for multiple years without needing to land using rechargeable solar energy batteries (Muchiri and Kimathi, 2016).

2.5 Summary

This literature review summarizes key relevant principles around UAS applications, IMT response, and co-integration. UAS and specific UAVs can collect various data but are constrained by battery life, weather, and legal regulations. Machine learning or other software can collect traffic data, reconstruct crash scenes, and measure roadway performance when video or images are collected. IMTs are also a powerful tool to increase roadway safety, and integration with UAS can lead to further community service improvements.

Private industry quickly develops hardware and technological solutions that integrate UAS and IMT responses. This literature review also includes a few case studies that illustrate this interaction. However, what is not shown is where this interaction may be most effective and what limitations are unavoidable or could be mitigated. This concern will be addressed in the following chapters based on the current research.

3.0 STATE OF PRACTICE

3.1 Overview

As stated in the literature review, UAS can be implemented in various ways to accomplish similar purposes. However, security concerns, limitations with UAS capabilities, and policy constraints must be addressed before complete integration. This chapter details the implementations of state organizations in livestreaming UAV footage as described through online resources and interviews with organization representatives. First, a brief explanation of how the different organizations were selected and interview practices will be provided. Then, each organization's UAS livestreaming practices will be described based on information gathered in the interview and other online resources. Finally, the case studies will be discussed, with key differences between DOTs identified and a commentary provided to compare those differences.

3.2 Methodology and Interview Practices

When compiling the literature review, select state DOTs were identified as industry leaders of UAS emergency response implementation based on published reports or online documentation of UAS livestreams. However, online details of these UAS integrations were often sparse or lacking in specific details to be useful. To gather more information, contact with an agency representative was necessary. The following section will list the agencies contacted for the State of the Practice, followed by a description of methods used to contact these organizations. Then, unsuccessful attempts to contact other organizations are summarized, and details of the interview format are provided

3.2.1 Contacted Organizations

Discovery of, and contact with, selected state DOTs identified as industry leaders of UAS response implementation occurred between April and October of 2024. The order of organizations presented in this report was determined by the approximate chronological order of when the interviews and information synthesis took place. Case study discussions occurred concurrently, so the chronological order may not be entirely precise. Instead, the main priority in this chapter is to organize the summaries in a coherent manner that also follows the process of discovery. The State of the Practice includes implementation practices, policies, and opinions from representatives of the following organizations:

- Massachusetts Department of Transportation (MassDOT)
- North Carolina Department of Transportation (NCDOT)
- Texas Department of Public Safety (DPS)
- Texas Department of Transportation (TxDOT)
- Ohio Department of Transportation (ODOT)
- Virginia Department of Transportation (VDOT)
- Delaware Department of Transportation (DelDOT)
- Michigan Department of Transportation (MDOT)
- Pennsylvania Department of Transportation (PennDOT)
- California Department of Transportation (Caltrans)
- Alaska Department of Transportation and Public Facilities (DOT&PF)

The discussions follow this order primarily because each successive interview or communication then informed subsequent communications with other organizations. Attempts were made to ask additional questions after initial interviews but were largely unsuccessful. Figure 3.1 illustrates these DOTs or state agencies, including states where contact was attempted but not successful, as further discussed in Section 3.2.3.

3.2.2 Successful Contact Attempts

Contacting individuals to interview for the State of the Practice occurred through various methods, including unsolicited emails, reaching out through personal connections or online professional communities, and contacting author lists. Each method had varying levels of success, and each agency was approached in the way that made the most sense with the information available. This section will describe how contact with the agencies (highlighted blue in Figure 3.1) were established.

The most challenging method to establish contact involved finding contact information for DOT employees and sending unsolicited emails. In many instances, news reports or online documentation established that a DOT had implemented UAS livestream or were using UAS during incident management but often lacked technical details and/or contact information for those implementing the technology. In the case of ODOT, an Every-Day-Counts (EDC) program presentation created by FlyOhio was found online. Further research into FlyOhio revealed other studies and contact information for supervisors and other state employees on a website. Those staff members were emailed, and contact was established when one of those individuals responded.

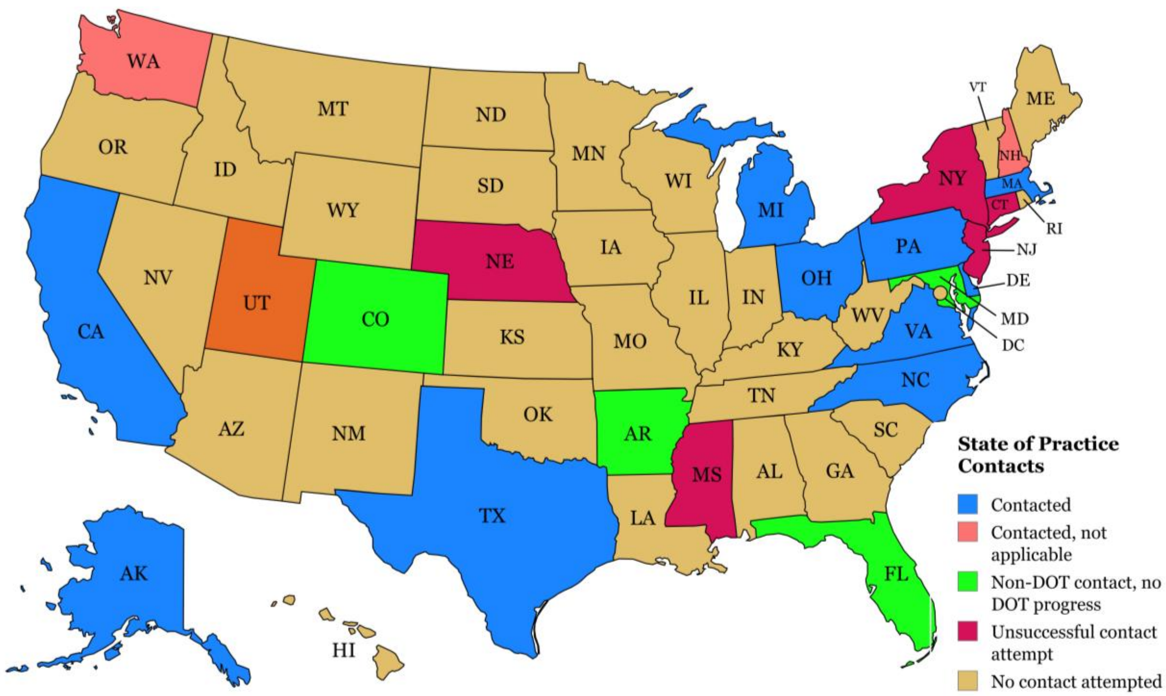


Figure 3.1: DOTs or other State Agencies Attempted or Successfully Contacted (Map created with mapchart.net).

When available, documentation with email addresses or names were incredibly useful when attempting contact. For example, an MDOT research report was found in the literature review, and an email was sent to key contributors. The email was forwarded to other coworkers, who then responded to the email. PennDOT was also contacted similarly through authors of a separate report.

Successful contact often took more than finding a name in a report to open communication with organization officials. With VDOT, a research article mentioned a key contributor, but finding an email address was particularly challenging. Instead, contact was initially made on LinkedIn as the individual was a secondary connection to one of the researchers. Similarly, during a research meeting with UDOT, members of the TAC commented that in a conference they attended, Texas DPS presented their use of tethered UAS. From there, the researchers found an online presentation, which included contact information for individuals from both Texas DPS and TxDOT. Those individuals were emailed, and a contact from each organization responded.

Professional communities were also used to establish contact. One such group, DroneResponders, develops collaboration between emergency responders, DOTs, and other UAS operators to discuss best practices for UAS integration in emergency response. The research team posted on various message boards asking to connect and a representative from MassDOT responded. This conversation provided information for MassDOT's system and was instrumental in providing the context in the beginning of the interview process. A post was also shared on a discussion board for the Institute of Transportation Engineers (ITE), a Community of Transportation Professionals. From there, an ITE member from DelDOT forwarded the message to a coworker, who then passed it on again to another coworker. Coincidentally, the researchers had also found a presentation made by this individual on UAS deployments but could not establish prior contact.

As contact was made with various DOTs, interviewees recommended several other DOTs to contact for this study. One of those was NCDOT. After an initial recommendation, researchers found multiple social media posts and reports by NCDOT on their deployment of UAS after Hurricane Florence in 2018. Contact with those authors and department heads was initially attempted with little success. However, a personal connection with an NCDOT contractor helped the research team to establish contact with the NCDOT UAS team.

Interviewees also frequently mentioned that the Alaska DOT&PF and Caltrans UAS programs were innovators in the UAS industry and could provide unique perspectives. For Alaska, one of the other DOTs provided an email address from a conference they attended, which connected to another individual and a conversation. Another DOT provided a contact for Caltrans. However, that effort was unsuccessful, and the research team resorted to emailing the department head and the general inquiry line for the department and DOT, which was forwarded to another contact and ultimately led to a conversation.

Connecting with individuals was most successful when a personal connection could be established. This approach was successful most of the time. When personal connections were unavailable, finding contact information through published research and public websites worked, but contact through that information had a lower level of success. Sometimes, phone calls were necessary to successfully connect with busy industry professionals.

3.2.3 Unsuccessful or Partial Contact Attempts

Although contact was pursued with 21 DOTs, the research team only successfully conversed with 13 of them. Two DOTs not included in the State of the Practice did respond or had people in the area contacted, but did not have programs relevant to the State of the Practice or were not actively pursuing developing UAS livestream programs. The following section will describe why these attempted contacts failed or why some DOTs were not included in the State of the Practice.

When beginning the State of the Practice, the research team watched an online presentation on UAS deployment for highway transportation (AASHTO, 2024). The training mentioned specific DOTs using UAS for various transportation-related purposes, including safety, aerial surveillance, and emergency response. Contact with each of these DOTs was largely unsuccessful. One was due to an invalid email, and the others never responded to the initial outreach. Efforts were made to find contact information or to establish personal connections, but these efforts were largely unsuccessful with several DOTs, including Mississippi, Nebraska, and New Jersey, as highlighted in red in Figure 3.1. Arkansas is highlighted in green as a non-DOT contact. A connection was established, and the individual acknowledged the potential use of UAS for livestreams but was unaware of how local DOTs were using this technology.

Two DOTs, Washington State DOT and New Hampshire DOT, were contacted but not considered for further discussion after initial communications when the representatives expressed that they were unaware of relevant programs in the DOT (as indicated in pink in Figure 3.1). Contact was initiated with the Washington State DOT through email. During that communication, officials indicated that the state has a tenuous relationship with UAS surveillance and the Fourth Amendment, with only some successful police UAS operations in recent years. It was made clear that Washington State DOT did not have a standing policy on using UAS to monitor traffic conditions and was not included in the study. Similarly, New Hampshire was contacted, but a conversation was not pursued after being informed that the DOT doesn't use UAS for livestreams. Research studies and other online media were also found indicating that Connecticut and New York could have applicable programs, but no contact information was available, nor could additional documentation be found. They are highlighted in red in Figure 3.1.

A member of ITE in Colorado contacted the research team, but the contact could not provide information on how the state DOT was using UAS livestreams. Instead, the team was recommended to reach out to police departments. Outreach to police departments and other first responders was attempted through DroneResponders, but no further connections were established. On DroneResponders, there was a sub-posting about a public safety group in Florida, but this was realized too late in the research process to be included in this report. In a separate conversation, another ITE member shared an article regarding drones as first responders in Maryland, but no additional contact was shared. These contacts, although helpful, did not apply to the State of the Practice and are highlighted in green in Figure 3.1. Florida is highlighted in green, illustrating both a contact and space for future contact.

Overall, attempting to contact DOTs blindly from a single reference was unsuccessful compared to when repeated documentation was available and research was published. Although many DOTs may use UAS, many have limited operations or do not publicize their use of UAS.

3.2.4 Interview Methods

The research team conducted interviews with as many DOTs and public organizations with UAV programs as they made contact with. Because the intricacies of UAS programs are not typically public knowledge, interviews were deemed as the best method to identify agency standards and situational practices. Interviews were conducted remotely via conference calls (video calls whenever possible). The number of participants who were involved in the interview varied from case to case, depending on how many individuals the agency contact determined was necessary. In many instances, the conversation largely remained between the researchers and one or two contacts from the DOT.

Agency representatives were asked a series of questions during the interviews including the background of their DOT UAS program, their personal history and experience in UAS deployment, how UAS livestreams are implemented by their UAS program, if UAS are used with incident management, plans for future implementation, and recommendations for other DOTs or groups to contact for the State of the Practice. Throughout the interviews, additional applications or unfamiliar considerations were discussed. With each interview, added context was discovered that inspired further questions or context for future communications. Additionally, tangents were often discussed as the researchers were very aware of their narrow perspective and pushed to explore anything that could potentially relate to the scope of the research. This, at times, led to discovering additional information, particularly about previously unfamiliar or developing technological innovations, or legal considerations and developments.

3.3 State-of-the-Practice Interviews

The following sections describe the State of the Practice in various organizations across the U.S. as collected from online resources and interviews with organization officials and representatives. These summaries are not comprehensive reports of all practices used industry-wide or in these organizations. Instead, they provide an overview of implemented practices and perceived benefits and challenges. The summaries will follow the order presented in Section 3.2.1.

Table 3.1 presents a summary of the case studies included in the State of the Practice. First, each case study is summarized with their key implementations of UAS, streaming services, and internet connection. Second, brief summaries of upcoming developments, key points, and additional comments for each DOT are summarized from the results of the case study interview.

Table 3.1: State of the Practice Summaries

Agency	Method Used			Upcoming Developments	Key Points	Other
	UAS	Streaming	Internet			
MassDOT	DJI	Conference call, integrated to RTMP	Cellular	Skydio fleet integration	Considered third-party streaming but it was too expensive for DOT needs	Early tester of tethered UAS, but updated systems are much better
NCDOT	DJI Fotokite	Conference calls (DJI) Fotokite internal streaming	Cellular	Starlink integration Local flight restriction dashboard BVLOS	Compared DJI and Fotokite tethered UAS. Fotokite performed better and was easier to use. High price may be prohibitive.	Publicizes UAS use during storm and emergency response Use of livestream for real-time traffic signal adjustments
Texas DPS	DJI Autel PDW	DroneSense	Cellular Starlink	Exploring the use of a Ford Lightning truck for tethered UAS	Strong emphasis on highlighting measurable impacts of each flight for continuous funding	Primarily border security, some integration with traffic management
TxDOT	Skydio	Skydio internal app	FirstNet	Drone-in-the-box desired for instant OnStar distress calls	Considered tethered UAS to be inadequate as operators cannot fly BVLOS	Strong emphasis on engineer engagement with UAS integration
ODOT	DJI	Airdata UAV	Cellular	Exploring Fotokite for analyzing recurring traffic events Drone-in-the-box	Used UAS to observe traffic during an eclipse and react accordingly to stopped traffic Night flights	Engineer UAS integration Use in public outreach Early COA use

Table 3.1 Continued

Agency	Method Used			Upcoming Developments	Key Points	Other
	UAS	Streaming	Internet			
VDOT	Pole mounted cameras	Conference call	Cellular	Further research in applications with VDOT restrictions	Facing serious regional restrictions with DC-related flight restrictions, privacy regulations, and response time limitations	If funding is available, Starlink could be used in rural areas
DelDOT	DJI Autel	Conference calls and Airdata UAV	Frontline FirstNet	Drone-in-the-box BVLOS flights	Notices that during high volume events, secured networks are strained	Tethered UAS are too expensive, prefers to swap batteries instead
MDOT	*Experimental only* DJI	YouTube	Cellular	Considering Tethered UAS integration	Would like to integrate UAS into DOT operations and is watching other DOT integrations before starting	Interested in tethered UAS applications with floodlights and traffic analysis
PennDOT	DJI Skydio	Internal UAS apps	Cellular	Improving UAS livestream integration practices and analysis tools	Considered streaming DJI video on an in-house solution (RTMP), but it was cost prohibitive	Conducted a study looking at livestream during construction and to test CCTV locations
Caltrans	Skydio Fotokite	Internal UAS apps	Cellular Starlink	Exploration of additional tethered UAS uses and further integration of lessons learned	Integrated floodlights with tethered UAS Uses Starlink to great effect in rural areas	Exploring use of tethered infrared cameras for landslide analysis
Alaska DOT&PF	DJI Skydio Drone-in-the-box	Internal UAS apps	Starlink	Tethered UAS BVLOS Advocate for DOT collaboration	Acquired multiple grants to test technologies and conduct case studies for proposed policies	Developing method for real-time data processing and photogrammetry

These summaries are designed to capture key implementation elements for quick reference and review. Upcoming developments concern new technologies and tools identified for future implementation within the DOT or DPS. Key points summarize unique implementation factors that distinguish the study from other case studies. The other column captures elements not included in the previous columns but provides additional context to the research. It should be noted that Michigan DOT is only in the experimental phase of their implementation and is so indicated in italics above their implemented technologies. Table 3.1 is not intended to be comprehensive, and the entire chapter should be reviewed to fully understand the breadth of each case study.

3.3.1 Massachusetts Department of Transportation

For years, MassDOT has implemented a simple UAV livestreaming system using an untethered UAV (Grazioso, 2024). This entails a simple high-definition multimedia interface (HDMI) connection from the UAS controller to a laptop, which then streams the data via a conference meeting platform (e.g., Zoom, Microsoft Teams, etc.). This system requires the user to have an internet connection and to maintain the conference streaming link. While the setup is simple, operators experienced poor meeting video quality and significant lag periods, especially in areas with limited wireless connection.

MassDOT developed a variation of streaming untethered UAV data. This involved creating a custom-built solution where data transmitted with an HDMI cable from the UAV is transmitted via a cellular network on the MassDOT real-time messaging protocol (RTMP) server. Once live, anyone with the correct internet protocol (IP) address can view the livestream.

A modem in an in-house solution box transmits the video feed and requires a separate power supply from the UAS. The solution costs about $2,000, including the hard case and other consumer products. Three team members typically operate the system during deployment. These roles include the UAV pilot, spotter/observer, and additional technical support

MassDOT utilizes this solution during crash response, “show and tell” construction projects, proof of concept for potential applications, and emergency drills. The MassDOT research and development team considered third-party streaming software, including

DroneSense, Airdata UAV, and Responder Cast. MassDOT officials considered this software inessential to operations due to the additional cost and the perceived minimal difference in video stream quality compared to conference meeting platforms and in-house solutions.

The MassDOT UAS fleet is comprised mostly of DJI drones, but due to security risks, MassDOT is exploring American-based platforms such as Skydio. In preparation for a potential DJI ban, MassDOT proactively hired an internal security manager to maintain compliance with federal and local regulations, monitor UAS-related regulations, adapt to technological developments, and manage UAS operator licenses.

When investigating tethered UAS streaming, MassDOT acquired a tethered UAS platform several years ago. The acquisition had minimal impact on MassDOT operations, but due to its relative age, it underperformed compared to modern UAS and MassDOT expectations. The prohibitive cost of an updated platform has prevented MassDOT from mitigating these limitations.

3.3.2 North Carolina Department of Transportation

In 2018, before Hurricane Florence landed in North Carolina, the NCDOT collaborated with the North Carolina National Guard and other public agencies to strategically place drone teams in several locations across the state (Karpowicz, 2018). After Hurricane Florence passed, NCDOT tasked these teams with gathering aerial surveillance and communicating critical infrastructure status in their regions to the central command center. NCDOT, state officials, and the media used the data to inform residents of road closures and the recovery effort status. This effort resulted in a smoother and coordinated response between the different agencies, including the Federal Emergency Management Agency or FEMA.

NCDOT conducted an internal pilot study considering the implementation of tethered UAS during traffic incidents or emergencies (Beaman et al., 2024). The camera network within NCDOT is well developed in urban settings but has significant coverage gaps along rural interstates, including along I-95 in east-central North Carolina. NCDOT researchers identified I-95 as the best-use case for UAS livestreaming due to its high concentration of high-impact crashes and incidents.

At the beginning of the study, NCDOT considered untethered UAS and pole-mounted truck cameras, but those alternatives were deemed inadequate for NCDOT's purposes. Instead, the research team investigated the use of tethered drones. NCDOT acquired a $50,000 research grant to purchase a Fotokite system and a Mavic 2 with a V-Line tether and evaluated their comparative effectiveness. Figure 3.2 shows these two systems side by side.

Researchers compared the two systems based on their ease of implementation, effectiveness during weather conditions, and user experience to streamline data directly into an operations network. The operators preferred the Fotokite because it was simpler to deploy than the Mavic 2 hybrid solution. Additionally, the Fotokite flew better during adverse weather conditions, and operators could stream live video through the Fotokite app. This meant the Fotokite solution was not dependent on third-party software or conference calls that were less dependable in the field. The Mavic 2 UAS video was streamed through Teams conference calls, making it more challenging to share the data, and requiring additional software.

(a) **(b)**

Figure 3.2: NCDOT - Tested (a) Fotokite and (b) Mavic 2 with Volarius Tether as Variations on Tethered UAS (Ciaramitaro, 2024).

Resistance to implementation was a challenge faced during pilot testing. In an interview with NCDOT officials, it was noted that operators often saw the implementation of the tethered UAS as a hindrance to their work. The operators reported minimal perceived return on investment for the tethered UAS operation. The operators did not feel actively engaged during the UAV deployment because there was little communication between the TOC and the ground crew. Additionally, regulations on tethered UAS required at least one individual to continuously monitor the system, reducing the capacity of the ground crews to address on-site developments.

A major crash that caused significant traffic detours occurred during the pilot study near a freeway interchange. Due to the unique and drastic change in traffic patterns, previous signal timing plans were insufficient to accommodate the changes in volume and queues, as shown in Figure 3.3. Engineers in the operations center used livestream footage to observe real-time traffic queues and manually adjust signal timings. Researchers identified tethered UAS deployment as an optimal tool to understand real-time queues and implement real-time responses to large-impact crashes. NCDOT concluded from this incident that tethered drones are effective in a large-scale crash response scenario with and without signals present (Beaman et al., 2024).

Figure 3.3: Integration of UAS Video in Real-Time Signal Calibration (Ciaramitaro, 2024).

Another limitation discovered during the pilot was poor reception in outlying areas and along the highway corridor. Satellite internet connections, such as Starlink, are used on select NCDOT trucks but were unavailable for implementation during the pilot study. Instead, mobile internet was used to stream the video.

An ongoing priority for NCDOT UAS officials is creating a digital dashboard to compile local UAS flight restrictions from public sources to minimize confusion before UAS implementation. Using open-source data, pilots in North Carolina will be able to quickly assess flight restrictions and act appropriately. Additionally, NCDOT is navigating concerns with state legislators on data stream security and implementing BVLOS flights. NCDOT acquired an FAA BVLOS waiver to install "drone-in-the-box" technology in areas at elevated risk of flooding and natural disasters. Pending the selection of specific technologies, the lessons learned from tethered UAS implementation may improve emergency response in North Carolina and the industry through collaboration efforts between DOTs and UAS professionals.

3.3.3 Texas Department of Public Safety and Department of Transportation

Texas DPS has an extensive UAS program, including 355 certified pilots who collectively fly over 52,000 flights annually with a variety of untethered UAS and log over 12,000 flight hours (Fritch, 2024). Most pilots operate UAS to complement their core responsibilities, and an internal team ensures that the program is up to date with training, licensing, maintenance, and execution. Every Texas DPS UAS mission is livestreamed in addition to other mission objectives. The majority of Texas DPS UAS are manufactured by DJI, with the fleet transitioning to Autel or the PDW C100 UAS. Texas DPS uses DroneSense for all flights, a third-party software that allows for a secure connection without using native UAS software. The third-party software creates a "magic video link" providing access to the livestream. This allows various organizations to access livestream footage and keeps the connection private and secure. Flight livestreams are streamed over a mix of mobile networks and Starlink internet.

Many UAS missions for Texas DPS heavily involve border security in seizing illegal transportation of drugs, monitoring incursions, and interrupting smuggling operations. The use of third-party software with easy-to-share links has allowed involved parties from various organizations to coordinate during cases of high interest. Texas DPS has an in-house cyber security solution to help secure the video stream, even while using potentially unsecure UAVs.

To justify continuous funding, Texas DPS shows the benefits of implementing its UAS program by highlighting measurable achievements. When operators use UAS in border incidents or as first responders, measurable impacts include pounds of drugs captured, lives saved, or other statistics. Publicizing the use of UAS internally has also helped to promote the UAS program and drive innovation. For example, outside of Texas DPS, drones are being used by first responders to deescalate responses by informing response teams before responding to the incident and are extremely valuable in scenarios where sending personnel could be dangerous.

Similarly, in traffic management scenarios, a drone can be used to approach vehicles in dangerous situations or to visualize incidents from positions that would be challenging to reach in person. Another potential solution is using tethered UAS. Texas DPS invested in a Ford Lightning electric truck to evaluate the effectiveness of continuously powering a tethered UAS. When deployed, the tethered UAS only used about 1 percent of the truck's battery per hour. With a mobile solution, teams responded faster to incidents with minimal preparation time.

When responding to crashes, Texas DPS often coordinates with TxDOT. Texas DPS investigates approximately 40 percent of fatal crashes on Texas roads. During these crashes, Texas DPS coordinates with TxDOT and local jurisdictions to manage and reroute affected traffic flow. Outside of fatal crash response, the most effective scenarios for TxDOT UAS deployment in traffic management are usually multi-lane closures, large vehicle pileups, and extended road closures.

Separate from Texas DPS, TxDOT also implements UAS during its operations (Roman, 2024). Each TxDOT division has a separate crew assigned to operate UAS as part of their responsibilities. Operators can experiment with various implementations, provided valid justification is established and flights stay within established guidelines. Most UAS pilots are engineers exploring how UAS technology can enhance their deliverables and streamline procedures. TxDOT engineers largely use Skydio drones during their missions. Depending on the application, engineers often find that UAS technology significantly improves their decisions, or they quickly realize that UAS are not a viable solution. The most common applications are in photogrammetry, 3D model creation, and thermal visualization of infrastructure.

Relating to UAS livestreams, untethered UAS are primarily used to show office personnel the real-time status of roads, evacuation routes, flooding, and the location of roadway debris. Video is commonly streamed on the Skydio platform cloud server, and shareable links are distributed to interested parties. At the same time, the UAS operator communicates with the operations center through phone calls, data-based conference calls, or two-way radio. TxDOT noted that the Skydio platform was highly dependable and effectively broadcast using the FirstNet-secured AT&T cellular network. Tethered UAS have been considered but determined to be inadequate as, under regional constraints, operators are still required to constantly monitor the device, reducing their operational capabilities. Drone-in-the-box solutions are also being considered, potentially to enable an instantaneous response to OnStar distress calls when a vehicle's airbags deploy.

3.3.4 Ohio Department of Transportation

With the release of the FAA Part 107 regulations in 2016, ODOT began implementing UAS during bridge inspections and construction monitoring (Gallagher, 2024). Before that point, ODOT closely collaborated with other agencies to acquire a COA after their unsuccessful attempt to become one of the FAA's UAS Test Sites.

The Ohio UAS Center is part of ODOT's DriveOhio initiative to promote smart mobility technology on the ground and in the air. Additionally, the Center manages, executes, and oversees all UAS services for ODOT and promotes innovative technologies and implementations. Within Ohio, this also entails coordinating with other state agencies, including the Ohio Environmental Protection Agency, Department of Health, and law enforcement, to standardize UAS software and implementation to simplify incident response and situation awareness. To share data, most streaming occurs over cellular or mobile internet. Verizon Frontline is being considered, but efforts to acquire Starlink systems may be more reliable as the volume and intensity of natural disasters that damage cellular towers increase, making cellular systems unreliable.

The Ohio UAS Center flies UAS equipped with various payloads, including thermal, hyperspectral, multispectral, metal detection, ground penetrating, and radiation sensors. Most missions are flown with “in-house” operators, facilitated by a Center-developed Part 107 training course. In addition to missions flown by UAS operators, Ohio trains staff engineers to operate UAS to assist in their responsibilities, fostering effective collaboration between technicians and engineers. Hiring third parties to accomplish these projects is sometimes considered but is generally more expensive than using an “in-house” operator.

Livestream flights are flown with DJI drones and streamed through Airdata UAV software over cellular connections with a video feed security system. However, acquiring NDAA-approved UAS, or Blue List UAS, is a priority. During an eclipse, ODOT officials were concerned about drivers parking on freeway shoulders to view the astrological phenomenon. By staging UAS pilots in CCTV dead zones, traffic operations could observe traffic conditions better and respond accordingly. In addition to their untethered operations, ODOT newly acquired a Fotokite UAS and plans to implement it in school zones, recurring events, and areas with extreme traffic conditions to better understand these complex situations and to adjust event plans. With the 2024 FAA Reauthorization, there is hope that individuals without a Part 107 license can operate a tethered UAS to gather data.

ODOT would like to use drone-in-the-box technologies to quickly respond to incidents across the state. However, deployment is limited by implemented BVLOS restrictions. ODOT is also considering flights at night, which require a specialty waiver from the FAA. When UAVs are used innovatively, benefits are frequently discovered to improve department operations and safety. ODOT communications teams also use drones to communicate about ODOT projects with the public, improving outreach and community engagement.

3.3.5 Virginia Department of Transportation

As mentioned in Section 2.4.3, VDOT sponsored a research study investigating UAS applications for TIM response (Alden et al., 2022). The research team used a DJI drone in a rural region for the study. While the researchers successfully executed UAS for TIM in a research setting, real-world applications of the research method and the specific technologies used (including an algorithm for traffic counts and analysis) were found to be cost-prohibitive and unsustainable for continuous VDOT operations at that time. When used by the research team in a university setting for VDOT, the use of UAS manufactured by DJI was not restricted, but similar use for the DOT would be limited, restricting the applicable scope of the research. Furthermore, VDOT officials believed there needed to be more investigation of operational gaps in CCTV for VDOT to target future implementation effectively (Paquin, 2024).

Many heavily populated regions in Virginia face airspace flight restrictions due to proximity to the presence of high-security facilities in and around Washington, DC. These flight restrictions make UAS implementation difficult in population-dense regions. Additionally, after the 9/11 attacks, the FAA established a restricted fly zone within 30 miles of Ronald Reagan Washington National Airport, with a no-fly zone within 15 miles. When faced with flying in restricted airspace, VDOT determined it would be easier to use a telescopic pole camera instead of a UAS, as a two-man crew on site to monitor and observe the UAS operation was ineffective. Additionally, using a pole camera is not subject to technology bans and does not require a Part 107 license or COA.

In western parts of Virginia, the terrain is remote and mountainous, often lacking the cellular service needed for livestreams. In regions with limited cell service, operators have tried recording UAS video for sharing instead of streaming it. However, efforts to share this video were found to add little operational value, particularly when there were significant gaps between the video recording and when it was shared. When livestreams are not feasible, and recordings are necessary, those videos can often mix key events, and quality checks can add further delays. It was estimated that 70 percent of Virginia doesn’t have the connectivity required for livestreaming to be effective (Paquin, 2024). VDOT is watching the Transportation Research Board and other DOT studies to assess the effectiveness of satellite connections in filling cellular connection gaps.

Streaming security is a significant challenge to VDOT’s implementation of livestreaming with UAS, including cyber-security and privacy laws. Virginia’s DOT information technology (IT) department has cybersecurity guidelines that restrict using unsecured data streaming to protect data and individual privacy. Additionally, privacy rules in Virginia require VDOT to lower the image quality of a public livestream to the point that the make or model composition of the traffic flow is undiscernible, reducing the effectiveness of the livestream. Degrading this data does add additional processing time and costs. VDOT did not consider secure third-party software as an option because of the additional costs. Additional FAA regulations became difficult hurdles for VDOT to navigate. While the Reauthorization Act allows a Public Safety Organization to operate a tethered drone without a Part 107 license (U.S. Congress, 2024), internal policies prohibit VDOT from using tethered drones without licensed operators.

Implementing UAS for TIM involves impracticalities and costs. During the interview, Paquin (2024) stated that most crashes clear in under an hour, so safety patrol trucks often arrive just as cleanup finishes. UAS operators experience challenges such as deployment time, clearing airspace, identifying hazards, and diverting resources from primary incident response duties. The costs and maintenance of UAS systems also pose funding challenges for VDOT. While VDOT acknowledges the potential of using UAS for TIM, particularly in maintenance and asset management, deployment efficiency, and data management, technology improvements, and policy adjustments are essential for the cost-effective implementation of UAS in VDOT emergency management operations.

3.3.6 Delaware Department of Transportation

DelDOT primarily uses DJI and Autel drones during their UAS missions. Initially, livestreams were run using an iPad controller. The video was sent to the Transportation Management Center (also known in other DOTs as a Traffic Management Center) via a private network SIM card with limited distribution capabilities (Day, 2024). The calls were relatively simple but often ran into connectivity and link-sharing issues. As the DelDOT UAS program expanded, it became necessary to find an alternative solution.

DelDOT's UAS program now uses Airdata UAV (a third-party software) for livestreaming and program management. Livestreaming video from the controller can be sent to different groups, including those outside of DelDOT, by sharing a uniform resource locator (URL) and a password. In addition, multiple UAV video downlinks can be sent at the same time to both a URL and the Airdata software, but unfortunately these flights cannot be viewed simultaneously. Using a central command station, DelDOT can view the video feeds on multiple screens to show the most complete image. DelDOT uses Open Broadcast Software to consolidate the multiple downlink images onto one video screen that can then be sent out to the viewer.

DelDOT UAS operators rely on mobile networks to stream UAS data. However, during large scale events such as NASCAR races and large music festivals, UAS operators have experienced slower mobile network speeds. When this happens, the video can be very choppy or nonfunctional. Although DelDOT does utilize secured data services through AT&T and Verizon to fix this problem, a viable solution has not been found. Ideally, in high traffic situations, first responders and safety personnel (including DOT response teams) have priority internet access through the secured network, but internet speeds are still limited in practice.

DelDOT has considered tethered UAS platforms, but the cost of a tethered UAS with its limited range versus a regular drone with a wide operating range is not in line with their UAS operation objectives. When DelDOT explored tethered UAS operations, operators shared that the constant demands of piloting a tethered UAS would limit their effectiveness in the field, particularly regarding their ability to provide situational awareness and damage assessments over a large area. Using tethered UAV also limits their ability to assist in scene clean-up. In the future, drone-in-the-box solutions would be used if BVLOS requirements can be solved.

Streaming from an untethered UAS platform has been seen as the most efficient alternative for incident response in Delaware, allowing operators to move the UAV freely as needed. DelDOT operators commonly have a dozen or more batteries at any given time and can keep untethered UAVs consistently in the air for extended periods. Battery replacements take a few minutes for the landing sequence and battery replacement. The only noted constraint is when the UAV begins to overheat, at which point the UAV must be swapped with another.

3.3.7 Michigan Department of Transportation

In 2021, MDOT sponsored a research project through the Michigan Tech Research Institute to investigate day-to-day implementations of UAS for transportation infrastructure (Brooks et al., 2022). One scenario involved using an untethered UAS platform to livestream a UAS video feed and conduct real-time traffic analytics. Although facing challenges with battery life and limited connectivity, the researchers proved that livestreaming untethered UAS video is possible and has various benefits over fixed cameras, including perspective from hard-to-reach areas and real-time adjustments to the view perspective.

During a conversation with MDOT officials (Bodell et al., 2024), the practicality of implementation noted in the Brooks et al. (2022) study was reported to be limited due to Michigan state policies prohibiting official use of UAS manufactured by DJI. Additionally, concerns were raised about the security of the livestream transmission. The research team streamed their data on a YouTube video, which, even as unlisted, still poses a significant security and privacy risk. Additionally, any data brought into the MDOT Statewide Operations Center (SOC) must be encrypted or otherwise secured to protect the MDOT cyber network. At the time of publication, MDOT does not actively stream UAS data during incident management but is actively considering ways to implement these practices.

Another option to provide livestreams to the SOC during crashes is to attach tethered drones to MDOT's safety service patrol vehicles. At this point, MDOT will observe other DOTs before implementing a tethered UAS program. Perceived benefits include rapid UAS deployment, the ability to attach floodlights to tethered UAV platforms for better visibility during crashes or incidents, and decreased time on-site for responders by providing better information during incident response.

It is also hopeful that traffic analysis algorithms can be connected to the video feed to provide real-time signal timing adjustments and detour management analytics. MDOT is concerned about regulations requiring the pilot to remain with the tethered UAS but hopes the updated FAA BVLOS rules will provide a general exception.

3.3.8 Pennsylvania Department of Transportation

PennDOT began its UAS program in 2018 and has innovated with UAS in many traffic-related fields. In an interview with a representative from PennDOT's northwestern district, UAS livestreams are primarily used for situational awareness, with expansions into bridge inspection, 3D model creation, and surveying (Mazzocchi, 2024).

PennDOT mainly utilizes UAS manufactured by DJI but has begun integrating Skydio UAS into its fleet in light of a possible DJI ban. Overall, PennDOT's experience with Skydio has been positive, although cost has been a limiting factor. With DJI operations, the internal DJI streaming capabilities are being used, but due to security constraints at PennDOT, this cannot be a long-term solution. One alternative to mitigate these concerns was to stream the DJI video feed on the CCTV network through an RTMP server. However, after PennDOT discussed options with their CCTV providers, solutions were available but were considered too expensive for implementation.

With a transition from DJI to Skydio UAS, the Skydio cloud server is a natural streaming solution. The Skydio cloud server provides livestream video on a secure network without needing to share unique links. Other groups in PennDOT have also used conference calls to stream UAS videos. Internet connection has been achieved through mobile hotspots with minimal coverage interruptions, except in dense forest cover areas where recordings must be shared instead of livestreamed.

UAVs were used in three case studies to demonstrate their effectiveness in increasing situational awareness for operators and interested parties in remote locations. These studies illustrate the benefits available without having to livestream video feed directly to an operations center. In Columbia County, PA, UAVs were used to test potential locations for a CCTV installation along I-80 (AASHTO, 2024). The typical process involved closing a lane or a shoulder and raising an employee in a bucket truck. Using a UAV to evaluate these locations, operators reported a significant decrease in the time it took to evaluate locations, reducing safety concerns for all involved. The final location selected for the CCTV was where only a UAV could evaluate, and it would have been impossible for conventional methods to determine.

In addition to UAVs assisting response teams, another case study by PennDOT demonstrated the impact livestreaming with UAS can have on remote parties. PennDOT was testing an innovative bridge installation solution (PennDOT, 2021) and used a UAS to livestream and record it. PennDOT reported that the livestream was helpful for project managers who could not be on-site to monitor the progress of the installation. After the installation was completed, the project team used the video to improve future applications of the technique.

Another case study of livestreaming with UAS assistance was in a remote-location blast-zone project. The blasting team needed to be a quarter mile from the site for safety purposes, but it would be tricky to see the status of the explosion and the debris in real-time. Additionally, just downhill from the blasting site was an active railway, where if debris did fall, it would need to be cleaned up instantly. PennDOT used a UAV to monitor the debris falling onto the railway and to keep the demolition team within safety parameters. Because of the unique angle the UAS provides, PennDOT prevented blast impact (or tertiary blast-related) injuries from the demolition.

Although these last few case studies do not specifically involve TIM, they demonstrate potential benefits for a UAS TIM program. The primary reported benefit from these use cases was situational awareness, specifically the ability of people not on-site to monitor the situation. The ability of UAVs to access different vantage points offers perspectives that ground teams cannot.

3.3.9 California Department of Transportation

The Caltrans Department of Aeronautics manages the Caltrans UAS program. From there, sub-charters are created for each operational division to use UAS. This section describes how UAS are implemented within Caltrans, specifically in District 1 (northwestern California) during construction and emergency response (Sutterfield, 2024a). Other districts may have differing UAS policies, but researchers only had the opportunity to interview the District 1 UAS Coordinator.

Caltrans employees utilize Skydio UAS platforms in daily operations to perform project documentation and earthwork quantity measurements. These operations primarily consist of collecting photographs and videos of construction or emergency sites then using photogrammetry and other tools for analysis. Untethered UAS are used for livestreaming, particularly during emergency bridge and infrastructure investigations, such as after earthquakes or other disasters. However, it should be noted that to stream the video, streaming services will often significantly downgrade streaming resolution for reliability. To get better images, recordings or more limited views (closer to the subject) are necessary. Implemented Caltrans policy requires all UAS flights, including tethered operations, to be flown under Part 107 authorizations. However, in the interview, it was remarked that the 2024 FAA Reauthorization (and subsequent edits to 49 USC 44806) is being considered for tethered UAS operations during public safety incidents (U.S. Congress, 2024).

Tethered UAVs are an emerging use case that are beginning to be implemented when responding to landslides, livestreaming memorial events, and monitoring work activities. For example, Figure 3.4 illustrates the deployment of a tethered UAS in Caltrans District 1, including the use of spotters and Starlink connection. One benefit of using tethered UAVs is that they can be used for extended durations, including as floodlights during nighttime activities, as seen in Figure 3.5. This allows for monitoring using attached payloads, which include visual, infrared, and other specialized sensors. Caltrans is also exploring the use of infrared during coastal landslides to visualize dynamic elements during fog or minimal visibility conditions.

Figure 3.4: View from a Fotokite in Caltrans District 1 (Sutterfield, 2024b).

Cellular coverage is often unavailable when streaming or transmitting data in northern California due to the mountainous topography, heavy foliage, and sparse population density. Thus, the district has begun using satellite communications, significantly increasing the reliability of the communications network. Satellite communications, including Starlink connections, can be available anywhere with a direct line of sight to the sky, even in areas with heavy foliage or box canyons.

Figure 3.5: 100,000 Lumen Floodlight from a Fotokite (Sutterfield, 2024b).

Due to local interpretation of federal policies and limited application within municipality jurisdiction, Caltrans District 1 construction UAS crews rarely have significant security or privacy restrictions. Most UAS flights occur within Caltrans right of way in controlled construction sites, which are considered public spaces. When sharing recorded data outside of Caltrans, identifying information and facial features are blurred with artificial intelligence tools, but livestreams are usually not externally available. Additionally, third-party software to encrypt data streams is less frequently utilized due to the private nature of shareable links and to simplify the connection process with interested parties.

3.3.10 Alaska Department of Transportation and Public Facilities

Due in part to its low population density, vast undeveloped land, and geographic diversity, Alaska has become a national hub for UAS research and development. The Alaska DOT&PF are respected industry leaders within the UAS community. In experimenting with various UAS solutions, Alaska primarily uses DJI and Skydio drones (Marlow, 2024). Although DJI has long been an industry staple due to its cost-effectiveness, Skydio platforms, such as the X10, have seen widespread adoption, particularly among agencies requiring NDAA or Blue List compliance. With a potential nationwide ban on DJI platforms, many agencies have begun transitioning to NDAA or Blue List UAS (Marlow, 2024).

Since 2018, several funding sources have allowed Alaska DOT&PF to build and expand their UAS program and to engage in innovation projects. These funds include support from the State Transportation and Innovation Council (STIC) and EDC monies for eligible technologies from the FHWA and the U.S. Department of Transportation (USDOT) Strengthening Mobility and Advancing Revolutionizing Transportation (SMART) grants. (USDOT, 2024).

Alaska DOT&PF regularly partners with the University of Alaska Fairbanks' Alaska Center for UAS Integration (UAF/ACUASI) to enhance UAS safety and ensure its seamless integration into the national airspace. As an FAA test site and lead for the FAA BEYOND program, ACUASI conducts research across the U.S., pushing the boundaries of UAS technology while developing best practices and guidelines for scalability and integration into commercial sectors. Alaska DOT&PF and ACUASI became the first in the nation to receive approval for the carriage of dangerous weapons onboard UAS, specifically for avalanche mitigation. This is one of the many successes resulting from ACUASI's work on BVLOS, which has been instrumental in supporting the FAA's efforts to standardize BVLOS flight regulations, often referred to as Part 108 rulemaking.

Alaska DOT&PF coordinates with other state DOTs to stay aware of innovations and to share best practices through FHWA-hosted Peer-to-Peer Exchanges. Many believe that coordination among state DOTs and federal agencies is essential for developing deployment standards among emergency response operators. Additionally, as regulations are constantly updated, organizations implementing UAS must adapt and coordinate with others to maintain compliance. This collaborative approach enables organizations to establish UAS programs efficiently, adhere to regulations, and enhance safety for all involved.

Starlink connectivity has made a significant difference when livestreaming UAS data. By providing internet coverage anywhere that the sky is visible, Starlink has essentially provided a direct link to the internet worldwide. At Caltrans, Starlink is primarily used when ground teams are in remote locations without any other form of connectivity and to enable BVLOS drone-in-the-box missions. In coordination with FAA oversight, Alaska DOT&PF has deployed drone-in-the-box solutions to monitor and visualize emergency incidents remotely, significantly reducing response times. Verizon Frontline was considered to provide an internet connection through a secured service, but its coverage is too limited for complete reliability. Where cost effective, some areas have used mini-cellular towers to extend network coverage.

Under the Alaska Rural Remote Operations Work Plan (ARROW) programs (funded by USDOT SMART grants), Alaska DOT&PF has deployed Skydio X10s and Starlink packages to monitor critical infrastructure and assist in emergency response (Alaska DOT&PF, 2024). Due to the unique nature of Alaskan deployments, Alaska DOT&PF also uses a rule of thumb known colloquially as the “172 rule,” which says that all cargo, cases, and technology must fit within a backpack in a Cessna 172 Skyhawk airplane with a single operator. By using Starlink, the internet connection is easily portable and adheres to the 172 rule. This technology minimizes the logistical demand on operators when flying or deploying UAS in remote areas.

With the ability to reliably connect to the internet from anywhere, Alaska DOT&PF is also developing a real-time data analytics system through the Environmental Systems Research Institute (ESRI). This system uploads remote UAS data to an ESRI server for real-time processing, visualization, and insights, which would be impossible without the Starlink connection. Future developments could include detailed real-time photogrammetry but require additional streaming technology and computer-processing power expansions for full-motion video.

Alaska DOT&PF is exploring using tethered drones for long-term operations, and monitoring. These platforms can also be used to vertically suspend floodlights for emergency response or construction zones, allowing ground crews to work on projects through the night. Due to their ability to operate continuously, tethered platforms are an effective solution for long-term monitoring and floodlight operations.

To address privacy and security concerns, Alaska DOT&PF uses a custom network to safeguard operations. The general policy ensures that the public can view publicly collected data but not sensitive personal information that may be collected during emergencies. In such instances, the video feed is either cut or blurred. Like television networks, which broadcast on delay, the UAS livestream is streamed on delay to filter content, allowing Alaska DOT&PF to filter content as needed.

For data security, Alaska DOT&PF utilizes its own edge data centers located across Alaska. This setup enables services that typically require internet access to be available "on-premises" via virtual private network (VPN) connections, allowing for faster and more secure operations without needing the UAS to connect to the manufacturer's servers. While this practice simplifies security protocols, it also limits Alaska DOT&PF's ability to livestream to external organizations, including first responders, media, and other stakeholders.

Many UAS used in emergency response are operated and owned by Alaska DOT&PF, facilitating legal data sharing between the DOT, police, and fire agencies. Ensuring open data standards is a priority, as they allow for scalability and better integration with emergency services. Alaska DOT&PF is also developing best practices for data management and privacy, including automatically deleting livestream data within 72 hours of capture. Additionally, artificial intelligence detects and filters personal or graphic content, ensuring privacy and security.

3.4 State of the Practice Interview Commentary

The application of livestreaming UAS video feeds is highly dependent on local legislative requirements, the needs of the region, and the funds available to the organization. Among the organizations described in the State of the Practice, all, to varying extents, have identified the perceived benefits of livestreaming UAS video feeds and are developing or planning to develop a program to harness those benefits.

To directly compare how one DOT utilizes drones and UAS livestreaming to another is often impractical and ignores the situational reality that each DOT faces. Each DOT faces unique challenges and are at various stages of implementation.

Of the 11 agencies interviewed, Alaska DOT&PF was the most technically advanced in UAS deployment. However, that is due primarily to collaborating closely with the FAA and UAF to develop UAS innovations such as Part 108. Other groups, such as Caltrans or Texas DPS, have considerable internal funding that allows for the creation of robust programs. However, their ability to innovate with modern technologies is limited. Despite those limitations, many DOTs find creative ways to experiment with approved technologies to solve complex problems or to improve systems.

Because of the difference between jurisdictions, not every DOT will experience the same benefits as another. For example, DOTs like MassDOT or VDOT could benefit by implementing technologies used in Alaska DOT&PF, such as Starlink, real-time data analytics and mapping, or completely air-gapping UAVs. But these technologies are not necessarily as applicable to those DOTs. MassDOT has such a small service area that their needs are met with a reduced program, without Starlink, and with fewer UAS needs. As such, MassDOT can afford a limited number of Skydio UAVs to replace their fleets of UAS manufactured by DJI. However, in a large DOT like Caltrans with various challenging terrains, Starlink is highly beneficial and greatly enhances performance.

VDOT's airspace restrictions limit much of what they can do with UAS. Another example is PennDOT's experience with an RTMP server. MassDOT implemented a system to stream UAV video on a DOT-run server; however, PennDOT found the same type of program to be cost-prohibitive for their uses. Similarly, while Texas DPS found tethered UAS to perform well in providing a livestream, other DOTs prefer to use untethered UAS instead. Untethered UAS requires frequent battery swaps but is more cost-effective and more straightforward for those DOTs. It is essential to identify and implement technological solutions that best fit the needs of the individual DOT.

Another consideration is that UAS deployment, like many programs, happens incrementally. A robust program requires staff with years of experience flying and operating UAS and using the resulting data to fill diverse needs. UAS programs can stall if the staff are unable to transfer knowledge, funding is inconsistent, or roles within departments in the agency shift. Each DOT has a unique history with UAS deployment, which heavily informs the state of their UAS program.

3.5 Summary

This chapter contains the methods used to contact individuals participating in the State of the Practice, practices from ten state DOTs and one state DPS when implementing UAS into incident management, and a commentary on the various implementation strategies and policies of the organizations. Although each agency has developed unique solutions to meet their local needs and mission objectives, general practices are evident. These include the benefits of using UAS for livestreams, balancing the need for a mobile platform with untethered UAS, and the benefits of a tethered system. Additionally, agencies primarily use approved UAS to avoid complications with CCP UAS bans.

As technologies and legal policies adjust, the exact brand names or forms of these livestreams will adapt, but several concerns will likely stay consistent and will be discussed in Chapter 4. These include secure and reliable streaming and broadcasting services, and utilization of FAA/NDAA-approved UAS technology.

4.0 SYNTHESIS OF PRACTICE

4.1 Introduction

Chapter 3 presented a summary of State of the Practice interviews that included a variety of implementation practices that DOTs and state agencies use when livestreaming UAS videos. When conducting the interviews for the State of the Practice, similar themes were often discussed and became clearer when consolidating notes from the interviews. This chapter summarizes the themes identified from the interviews. The findings presented in this chapter and subsequent chapters are from personal beliefs and opinions collected during the State of the Practice, combined with technical details from online resources. First, the implications of security concerns with DJI drones will be discussed, and mitigations will be proposed. Then, the effectiveness of tethered UAS and their optimal role will be evaluated from survey comments. The role of satellite internet connection will be discussed and evaluated with regard to practicality. Finally, the need for secure streaming will be considered, and viable solutions will be presented.

4.2 Considerations for DJI Ban and Security Concerns

State DOTs and other agencies highly utilize DJI drones for UAS incident management. DJI is primarily selected for its low prices, high-quality and convenient software, and superior drone platforms. Although many of the benefits of livestreaming are possible with other UAV platforms such as Skydio, Parrot, and Freefly, these systems are considerably more expensive than DJI for comparable quality UAVs. This section will discuss the security concerns with using UAS manufactured by DJI and alternative solutions found by state DOTs faced with these concerns.

4.2.1 Security Concerns with DJI Drones

As previously mentioned in Section 2.3.2, due to the perceived connection of DJI drones with CCP interests, national security agencies in the U.S. are deeply concerned about their use. The National Security Agency (NSA) and other concerned parties have not publicly disclosed the specific details of this threat to national security; however, the details shared with the U.S.

House and Senate have the potential to drastically alter the UAV landscape in the U.S. Proposed legislative bans would prohibit the sale or import of UAS manufactured by DJI and allow the FAA to place them on a no-fly list, potentially grounding those already in use. There are also discussions to add other CCP UAS manufacturers and companies in politically adverse nations to a national ban, including Autel UAS.

4.2.2 Alternative Solutions to DJI Drones

At the time of publication, DJI holds a large UAS market share in the U.S. and is one of the fastest-growing UAS manufacturers worldwide (Alvarado, 2023). This aggressive growth and large market share make it challenging for other UAS manufacturers to compete in the UAS market. American UAS manufacturers struggle to develop UAS to meet the technological expectations from UAS pilots while competing with DJI’s low prices. However, with a potential CCP UAS ban, DOTs and government agencies are turning to the American-based UAS manufacturer Skydio as a substitute for DJI drones.

Skydio drones typically cost three to five times as much as a UAS manufactured by DJI and are perceived to be of lesser quality. However, Skydio is noted for having excellent cloud-based services, which can make livestreaming easier as will be discussed later in this section. Selected Skydio UAS are included on the “Blue UAS Cleared List,” as authorized in the 2020 NDAA to regularly recognize secure UAS platforms and cameras (Defense Innovation Unit, 2024). Other platforms on the “Blue” list include UAS from Parrot and Freefly, among a dozen other manufacturers.

Although DJI may hold the largest market share with the highest quality product, when purchasing a UAV, state organizations should consider the associated security risks of purchasing DJI drones. While it may currently be legal for public organizations to fly DJI drones, the threat of a potential ban has driven state DOTs and public organizations to look to other brands. Organizations that purchase low-security-threat drones are better prepared to avoid UAS program failures in the event of a national ban.

4.3 Uses of Tethered Unmanned Aerial Systems

Multiple state DOTs and public organizations are considering implementing tethered UAS. Because of their simplified deployment and continuous power source, tethered UAS have been used in critical incident management contexts. This section will outline the benefits of using a tethered UAS, followed by the barriers to implementation.

4.3.1 Benefits of Using a Tethered Platform

The benefits of tethered UAS platforms include simplicity, consistency, and longevity. Tethered UAS have an indefinite flight time as long as they are connected to a power source. When connected to a running car, emergency generator, or other battery, tethered UAS bypasses the challenge of changing batteries or swapping UAS to maintain a constant livestream. This allows for greater efficiency in extended-length projects and incident response scenarios.

Additionally, the tether feature also decreases the impact of inclement weather. Because tethered UAS are fixed to a deployment station, they are less susceptible to the impacts of wind and rain. Tethered UAS are affected by harsh weather conditions, but they add versatility and reliability in emergency response. Additionally, tethered UAS are often simpler to operate than untethered UAS. Considering these advantages, tethered UAS are most effective in scenarios with long response times and where durability is a higher priority than versatility. DOTs typically reported these as pre-planned events, nighttime construction projects, or large crash cleanups.

Some DOTs have tried using tethered UAS for standard crash response but find that with regulations requiring a line of sight from the operator to the UAS, operators that would normally assist in crash response are unable to do so. However, some organizations interviewed interpret the FAA’s BVLOS rules differently. In some interviews, organizations indicated that ground crews could operate a tethered drone without maintaining a visual observer if they are within line of sight. This practice seems inconsistent with FAA regulations, as a line of sight from the operator to the UAS is required. However, during long-term events, it was considered valuable to have a staff member observing the UAS to maintain a live feed. FAA regulations will continue to evolve, meaning that any public safety agency should regularly review applicable policies and regulations and ensure that their interpretation of those guidelines complies with FAA standards.

In the 2024 FAA Reauthorization Act, section 49 USC 44806 was modified in the U.S. Code regarding the use of UAS by public agencies and the use of tethered UAS by public safety entities. Under this regulation, public safety agencies are authorized to fly tethered UAS without a Part 107 license or COA, provided they fly under 150 feet in B, C, D, E, or G airspaces obeying other airspace restrictions, and above 150 feet only with permission (U.S. Congress, 2024). This exception is designed to simplify the UAS implementation process for police and fire crew response.

The main benefits of this exception include UAS deployment without needing to complete a waiver, and the use of the system does not require the operator to obtain licensure. By allowing agencies to control their operations, department turnover, especially in volunteer forces, is easier to manage. For a DOT to operate under this exception, the operating group or DOT must be classified as a public safety organization. However, the use of tethered drones under this exemption was not captured by the State of the Practice. It is unclear how a DOT, or the emergency response personnel within a DOT, may be classified as a public safety organization, subjectively meeting the definition laid out in code, as "an entity that primarily engages in activities related to the safety and well-being of the general public, including law enforcement, fire departments, emergency medical services, and other organizations that protect and serve the public in matters of safety and security" (U.S. Congress, 2024).

4.3.2 Challenges when Using a Tethered Platform

Disadvantages of tethered systems include limited aerial mobility, initial capital cost, and evolving regulations. While the tether feature is advantageous for simple deployment, the tethered UAS cannot quickly change its lateral, non-vertical position, restricting the pilot to an anchored view. This means tethered platforms are inefficient in scenarios that mandate multiple perspectives, mobility, and speed. These scenarios include bridge inspections, crash reconstruction, standard roadway clearance projects, and other shorter-response scenarios.

Tethered UAS systems also typically cost more than their untethered counterparts. For example, the Fotokite Sigma was designed for first responder use and is popular for its livestream capability and simplicity of deployment and operation. However, the Fotokite system typically costs over $30,000.

Although minimally discussed in the case studies, hybrid tethered solutions, in addition to indefinitely tethered solutions, can resolve some of these concerns. Hybrid tethered systems allow the UAV to be both tethered and untethered, depending on the needs of the mission. DJI offers a hybrid solution where a standard untethered UAV can be attached with a tether for longer flights. The DJI tethered systems would also be likely subject to a national ban. Other solutions include a UAV that is primarily tethered but can disconnect from the tether mid-flight. It is unknown if any systems enable an untethered drone to become tethered in the middle of a flight without pilot intervention (i.e., manually reattaching the tether). Hybrid tethered systems were not mentioned in the case studies discussed. While more expensive than a typical untethered package, hybrid solutions offer some benefits of a tethered system without being as expensive.

The primary tethered UAS in the U.S. is the Fotokite. One key element of a Fotokite is that it is simpler to operate than other hybrid or untethered UAS, requiring less technical expertise or attention. Multiple public safety organizations and traffic groups use Fotokite for extended livestreams, stage lighting over construction sites, etc. Reviews are highly favorable, but some concerns include the high price and the slight tendency of the roof-mounted solution to overheat on extended deployments.

Tethered UAS can be highly beneficial, but their mobility limitations may hinder their widespread or universal use. Tethered UAS are useful in situations with longer incident response times and predetermined scenarios while being ineffective in day-to-day response situations. When funds permit, tethered UAS add value and versatility in emergency response and livestreams.

4.4 Role of Satellite Internet Connections

A large concern of this research was how various DOTs were able to livestream securely in areas with poor or limited internet connection. This concern was not unfounded, as for many DOTs and emergency organizations, internet connection is a major consideration in the process of livestreaming with UAS for incident management. In many operational regions, cellular connections are typically sufficient. However, alternative solutions are required in remote areas, in regions with high traffic interference, or in cases when the livestream must be secured. In this section, the role of satellite internet functionality in incident response in remote areas will be discussed, followed by a summary of first responder-secured internet services.

4.4.1 Satellite Internet Functionality

Strong internet connection is essential for sharing video feeds from the UAS to an operations center. The most common solution is creating a mobile hotspot from a cellular device or a modem. Many incident response teams use air cards in their response vehicles to create mobile internet hotspots. In addition to vehicular modems or other mobile connection solutions already in response vehicles, some DOTs use a mobile hotspot modem deployed with the UAS independent of the response vehicle. By having a separate device to transmit this data, the operations of UAS missions are not limited by the technology in the response vehicle. Provided that response kits are correctly prepared in advance, pre-staged materials in a response vehicle do not limit responders. Mobile network solutions work well in regions with adequate cellular coverage, but the networks regularly struggle in rural environments or during high traffic (e.g., concerts, sports events, operations in high urban areas, etc.).

In remote areas, satellite internet connection was found to be the most effective way to supplement gaps in cellular coverage. Based on the interviews conducted for this research, the Starlink network is the most frequently used satellite network among DOTs for emergency response. Satellite connection has been available in a limited form since the 1960s, but with the rise of commercial space exploration, public access and the reliability of these networks have grown exponentially (Taylor, 2024).

The Starlink system has an extensive satellite network in low earth orbit, providing a consistent network worldwide with latency as low as 25 milliseconds (Starlink, 2024a). Satellite internet functions similarly to mobile networks, where data are streamed from a computer network, but instead of being transmitted by cables to transmitters, the data are transmitted wirelessly to a satellite network, and, from there, to receivers in homes, planes, boats, or wherever needed, as shown in Figure 4.1.

Starlink satellite internet requires a clear line of sight to the atmosphere for optimal internet connections. In one interview, a Starlink user mentioned how internet connection was possible in heavily forested areas, but speeds were generally slower. Starlink advertises strong connection during cloudy events or storms due to their satellites being in low earth orbit, but some disruptions occur during heavy precipitation or severe weather events (Starlink, 2024a). Implementation among DOTs and state agencies has gradually revolutionized internet connection in remote regions. Connection to the internet is possible through various models of Starlink Wi-Fi routers purchased with the internet plan.

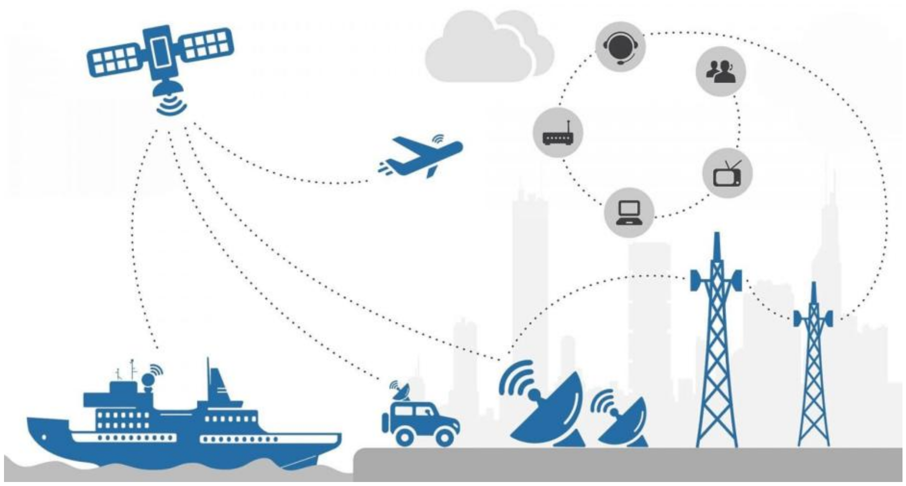


Figure 4.1: Illustration of Satellite Internet (BusinessCom Networks, 2024).

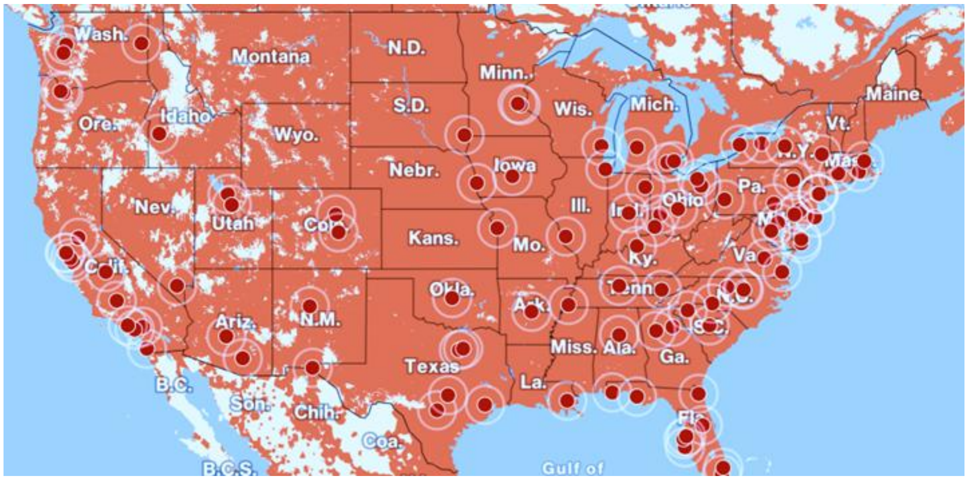
Figure 4.2 shows the 2024 Starlink coverage worldwide, with full coverage shaded in light blue (e.g., U.S., Europe, and parts of South America, Oceania, and Africa). Some areas are at capacity, and users can join a waitlist to gain access, shown in slightly darker blue shades, including Ukraine, Antarctica, and small regions in otherwise full-service areas. Areas in darkest blue shades (including Greenland, greater parts of Africa and Asia, and select parts of South

America) are regions where the network could be available but is limited by local regulations or hardware limitations. The gray areas, including Russia and China, are regions where coverage is not possible at the time of publication (Starlink, 2024b). The Starlink connection hardware can be mounted to buildings and vehicles or carried through a mobile platform, all purchased separately from the subscription-based service.

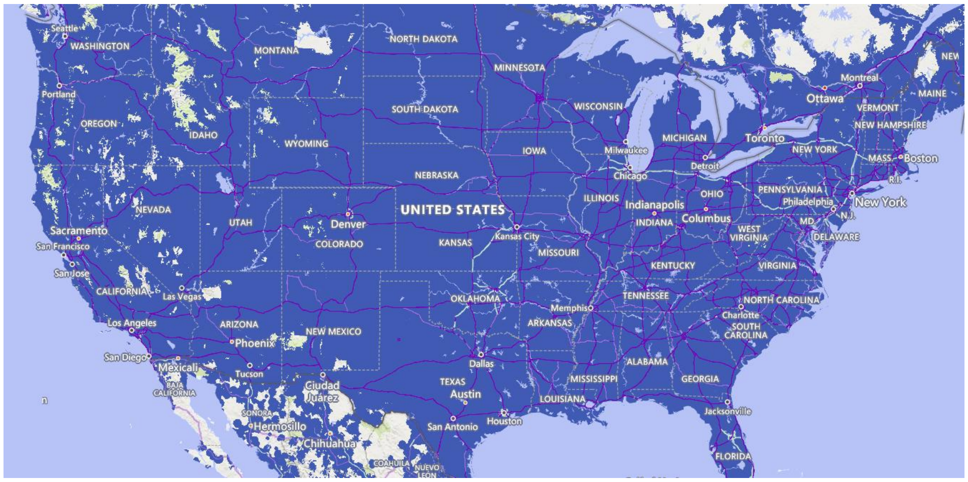
Figure 4.2: Worldwide Starlink Coverage (Starlink, 2024b).

<u>4.4.2 Secured First Responder Internet Services</u>

Another internet connection service considered in practice is using first responder networks such as FirstNet through the AT&T network or Verizon Frontline. Figure 4.3 compares Verizon, AT&T, and Starlink coverage. FirstNet and Frontline are built off AT&T and Verizon, respectively, and both provide secure, dedicated access to first responders and security providers. Verizon and AT&T have similar coverage maps, but AT&T has slightly better coverage in the Intermountain West region, while Verizon has specialty coverage in select large cities. Depending on the selected plans, the purchase of locked devices, specifically for that network or service, may be required. Starlink has excellent coverage in most of the U.S., including remote regions, with some select areas pending approval or additional infrastructure. Starlink also advertises its services to first responders, sometimes providing free emergency services and marketing its encryption protocol (Starlink, 2024c).



(a) (Verizon, 2024a)



(b) (AT&T, 2024)

(c) (Starlink, 2024b)

Figure 4.3: Wireless Coverage for (a) Verizon; (b) AT&T; and (c) Starlink Internet.

In some DOTs, ground teams must use secured first responder-specific networks when working remotely due to security and privacy concerns. However, because secured networks rely on mobile networks, bandwidth may be limited during high-traffic events, which can cause overall slower speeds, even on prioritized bandwidths. When selecting an internet provider, a balance must be struck between reliable coverage and the price of that coverage. Secured mobile internet is cheaper than satellite internet, but satellite internet may be more dependable than secured mobile internet. Satellite internet may not meet agency-specific requirements for secured internet as required by FirstNet or Frontline connections.

For areas with limited cellular connection, satellite internet offers an effective solution to supplement regular cellular coverage plans. Both satellite internet and first responder networks have subscription costs and initial hardware acquisition requirements. When considering internet connectivity solutions, organizations should consider the cellular internet constraints of their region and determine if supplemental connections are required. While not necessary in all cases, the use of satellite internet and first responder networks can improve stream security, while satellite internet might be required to connect to the internet in some areas.

4.5 Secured Streaming Solutions

When selecting UAS platforms, organizations consider livestream capability to determine which streaming platform will best meet their operational needs. There are various solutions with different restrictions, benefits, costs, and practical uses. This section will discuss different UAS livestreaming platforms, including native app software, conference calls, and commercial third-party streaming software, followed by security concerns when streaming and the use of in-house streaming solutions.

4.5.1 Video Streaming Platforms

DJI and Skydio systems have internal, native streaming services with their UAS platforms. The DJI Fly app creates a unique link for each livestream that can be shared. Reviews are fair and the system is thought to work well. The Skydio Cloud website can also create a shareable link or provide streaming access through a multi-user group dashboard where individual UAS in the agency network can be monitored simultaneously. When a UAV is live and streaming, anyone with access to the Skydio accounts linked to the dashboard can view the video. As reported in various interviews, DOTs using the Skydio platform find it to be dependable and adequately secure for video streaming.

Another common streaming solution is the use of conference call software, such as Microsoft Teams (most common) and Zoom. By changing the camera input to the UAS and/or sharing their screen, organizations have successfully livestreamed with conference software. Platforms allowing the UAS to be the user camera are usually more effective, as screen sharing has been found to be transmitted at lower quality. However, this software is typically less effective, even when shared as a camera in areas of poor internet connection. Additionally, depending on the DOT security protocol, adding members outside the department to the conference call may be challenging, limiting access to the video stream.

Multiple organizations also use third-party solutions, such as DroneSense, Airdata UAV, and Responder Cast, with various levels of success. The nature of the technology industry is such that software specifics are in constant flux. As such, a detailed exploration of individual software will not be performed, but rather, the key features of the software will be illustrated. As reported in Chapter 3, each DOT or agency chose solutions to best match their needs. For example, some of these systems provide a shareable link secured by a personal identification number (PIN). This provides the accessibility of a link while providing greater security.

Some of these platforms also include a UAS monitoring database and can help track maintenance, UAS personnel assignment, licenses, pilots, battery status and more, depending on the platform. This last option is highly valuable for DOTs looking to better organize their UAS deployment in ways that spreadsheets or UAS-specific software may not be able to do. With all UAS internal streaming services (native app, conference calls, third-party), image resolution is degraded to a lesser quality, compared to the original camera resolutions of 2-4K in still-shot or recorded video. Thus, if a detailed analysis is required, sharing recorded video should be considered.

4.5.2 Security Concerns and Use of In-House Solutions

A common operational constraint is the need for a secured streaming service for sensitive video feeds, particularly during serious incidents. When programs are in their discovery phase, public streaming platforms such as YouTube, are used but pose significant security risks and are rarely used in long-term, established practices. Security specifications vary among DOTs, and there is little guarantee that a program authorized with one DOT would be accepted by another. Common solutions include using a secured mobile or satellite network and requiring a PIN when sharing a video link. More advanced solutions require an encrypted video stream or restricted server access. Some video streaming platforms provide an encrypted video stream and may be sufficient. Other security platforms require additional video encrypting software. In a developing world of cybersecurity, UAS programs should remain in close communication with their respective IT departments to monitor implementation security.

Not finding optimal solutions with available technologies, some organizations turn to custom-built, in-house solutions. While the technical specifications of these solutions are beyond the scope of this research, a brief mention of the benefits and limitations of custom-built solutions is relevant. Many of these systems involve connecting the UAS camera or video output, to an existing DOT or state server. This can be done by treating the stream as another traffic camera without a fixed location or streaming the data through the network. Custom solutions can be initially expensive and require long-term expertise to design, create, and use. Organizations that use custom-built solutions report that in-house solutions are better at meeting organizational needs and are more straightforward to use in the long run. If funds are available, custom-built solutions are powerful tools to effectively meet the needs of livestreaming with UAS for TIM.

When selecting specific streaming software, the DOT may consider the cost of implementation, ease of use, the implementation needs of the department, and the long-term sustainability of deployment. Careful consideration of the available options, together with discussions with DOT and state IT officials and UAS operators, should be part of the streaming software selection process.

4.6 Summary

This chapter reviewed several key findings from the State of the Practice, including the role of DJI drones, tethered UAS, satellite internet, and secured streaming services. These findings will influence practice differently depending on UAS deployment history within a given DOT and applicable legal interpretations. However, these findings are critical in effectively understanding UAS long-term applications of livestreams and establishing reasonable deployment expectations. Specific technologies and their implementation will be discussed in the next chapter, and selecting the appropriate solution will require understanding the local UAS deployment environment and the needs of the DOT.

5.0 CONCLUSIONS

5.1 Introduction

The primary objective of this research was to synthesize case studies and develop a State of the Practice concerning how DOTs across the country use UAS to livestream during traffic incident response. To create a State of the Practice, the research team conducted virtual interviews with 10 state DOTs and one state DPS and summarized them in a State of the Practice. The second objective of this research was to develop recommendations specifically for UDOT to further implement UAS livestreams during TIM response. This chapter describes the research findings and related limitations and challenges. The recommendations and general guidelines for implementation will be described in Chapter 6.

5.2 Findings

There are a wide variety of potential solutions to implement UAS livestreams. Selecting the appropriate solution involves many considerations and often trial and error. This section will first present summary tables for implemented technology, implemented UAS, streaming services, and internet connection, followed by a brief description of each.

5.2.1 Implemented Technology Summary Tables

Table 5.1, Table 5.2, and Table 5.3 summarize key elements and technologies for each consideration with specific solutions. Each table compares solutions based on their individual features, including their approximate cost, functional capabilities, quality of service, benefits, and limitations. Information in these tables is based on discussions in the State of the Practice, from online resources, or otherwise based on the author's subjective knowledge. As technology advances, some solutions may not be available or may differ from what is explained in this section, but the general principles can assist in selecting relevant solutions.

Table 5.1: UAS Platform Solutions

UAS Type/Brand	Approx. Cost	Native Livestream Capability	Benefits	Limitations
Untethered **-** General		HDMI output from the controller, native app, or third-party software	Versatility in application, mobility	Part 107 regulations require constant supervision
DJI (DJI, 2024)	$1,000-$5,000	DJI native app (DJI Fly App) to RTMP Compatible with third-party software	Inexpensive, high quality	Security concerns, potential upcoming nationwide ban
Skydio (Skydio, 2024a)	$12,000-$20,000	Skydio native app to cloud service Compatible with third-party software	Versatile cloud service for livestreams On NDAA Blue list (approved UAS)	More expensive and lower quality Facing battery supply shortages from CCP restrictions
Tethered **-** General		Native apps and potentially third-party software	Potentially bypasses Part 107 regulations Unlimited flight duration	Expensive platforms Limited applications Requires a constant power supply
Fotokite (Fotokite, 2024)	$30,000	Native app	Simple deployment Tailored to first responder groups Secured network	Limited travel range, operator must remain in line of sight of deployed UAV
V-Line Pro (Volarious, 2024)	$16,500	DJI companion application	Converts a DJI untethered UAV into a tethered UAV	Security concerns Additional expense to UAV purchase
Drone-in-the-Box	$10,000-$350,000	Various: links, cloud servers, etc. Pending legislation for widespread applications	Decreased response time to incidents Allows for UAS to be staged at key locations	Limited by BVLOS regulations Requires constant power supply and maintenance after installation

Table 5.2: Video Streaming Solutions

Method	Add. Cost	Security Quality	Security Permissions	Benefits	Limitations
Native App **-** General	No		URL link to RTMP	Simplicity and high quality	Limited ability and security
DJI (DJI, 2024)	No	Low	URL link to RTMP	Intuitive	Security concerns
Skydio (Skydio, 2024b)	No	Medium to High	"ReadyLink," or cloud service	Comprehensive cloud service	Lower quality camera
Fotokite (Fotokite, 2024)	No	High	URL or QR code	Multiple simultaneous viewers	High purchase price and low lateral UAV mobility
Conference Call **-** General	No		Anyone within organization	Using software already used by organization	Low quality in regions with poor connectivity
Teams *Google* *Zoom*	No	Medium to High	Link or meeting invitation	Easy access for operations personnel	Low quality video Limited sharing outside DOT
Third Party **-** General	Yes		Link or server access	Various add-ons depending on the software	Additional costs
DroneSense (DroneSense, 2024)	Yes	High	Anyone with "magic link"	Includes fleet management system	Limited use, mainly iOS, DJI, and Autel UAS
Responder Cast (GenPac Drones, 2023)	Yes	Low to High	Sharing may be limited to organization	Simple interface, limited documentation	No fleet management and limited sharing
Airdata UAV (Airdata UAV, 2024)	Yes	Medium to High	URL and PIN to access	Data analytics, UAS Fleet management	Concerns with security and UAS compatibility

In-House Solutions - General	Likely	Medium to High	Depends on setup	Built off agency system	Requires in-house expertise to create and maintain

Table 5.3: Internet Connection Solutions

Method	Approx. Cost/ Month	Internet Coverage Quality		Benefits	Limitations
		Urban	Rural		
Mobile Internet - General	$60	Medium to High	Low to Medium	Already used Simple to implement	Mediocre quality in rural settings or during high-traffic events Unsecured
Secured Internet - General				Gives priority to first responders Secured network	Service may be limited during high-traffic events
FirstNet, AT&T (FirstNet, 2024)	$40-$45	Medium to High	Low to Medium	Fair coverage of Intermountain West Region	Smaller use network, third-party developed
Verizon Frontline (Verizon, 2024b)	$60	Medium to High	Low to Medium	Advertises stronger internet connections in select cities	Poor coverage of the Intermountain West Region
Satellite Internet Connection - General				Provides connection to rural areas	More expensive depending on the package
Starlink (Starlink, 2024a)	$120-$5,000	Medium to High	Medium to High	Solutions marketed to first responders Encryption documented	Requires additional hardware (approx. $600 per location) Aerial optics required
HughesNet (or Viasat) (HughesNet, 2024;	$60-$150	Low to High	Low to High	Good coverage Can run on prior satellite infrastructure	Not as secure and more data caps Higher latency

Viasat, 2024)		Limited portability; semi-permanent installation

The approximate cost was collected from online, publicly available resources. The livestream capabilities in Table 5.1 and the security permissions in Table 5.2 were generalized from interviews and promotional materials for the different technologies. The additional cost column in Table 5.2 represents costs in addition to purchasing the UAS. For example, livestreaming from a Fotokite does not require additional payment, but in the limitations column, it is indicated that the system overall is very expensive. In Table 5.2 and Table 5.3, quality of security and internet service, respectively, are estimated. These measures are largely subjective and were estimated from information gathered during interviews, the products marketing materials, and online reviews of the product. These metrics can also be used to rank the technologies described in the tables, although comparisons to technologies not included would be unadvised without further standardization. The technology limitations and benefits were compiled from the State of the Practice and other online resources. These lists are not exhaustive of all possible comparisons and they attempt to succinctly summarize the key findings of the research.

5.2.2 Implemented Unmanned Aerial Systems

A variety of UAS technologies exist to meet diverse needs. The primary UAV manufacturer is DJI. However, due to political conflicts between the CCP and the U.S., UAS manufactured by DJI are becoming less feasible for long-term use. An official list of approved UAS was authorized by the 2020 NDAA, and more than 20 UAVs are listed at the time of publication. The primary UAS not manufactured by DJI in use by most DOTs is the Skydio X10. Some DOTs use Autel drones, which may also be banned in future legislation due to their CCP connections. Additionally, recent Chinese sanctions on Skydio batteries limit the expansion and use of Skydio UAS (Skydio, 2024c).

A variation also used by DOTs is tethered UAS. The cheapest version is to create a hybrid solution, such as the Volarious V-Line Pro, which can transform an untethered UAS into a tethered UAS. However, a simpler solution, albeit significantly more expensive, is to use a Fotokite. These systems have great reviews and are well known for their simple and secure streaming operations. In the coming years, the use of drone-in-the-box technologies may be feasible. Several drone manufacturers, including Skydio, are developing these technologies, but they can only be deployed once favorable legislation is established.

If providing a livestream connection is the sole purpose of UAS implementation, then tethered UAS may be the optimal solution. If other capabilities are also needed, and adequate funds are available, purchasing tethered and untethered platforms would be advisable. If other capabilities are needed, but inadequate funds are available, purchasing untethered UAS with additional batteries may be the preferred option. Additionally, based on local restrictions on UAS procurement, cheaper UAVs may be available to expand UAS selection.

5.2.3 Implemented Video Streaming Services

The variation among streaming services is as widespread or even more so than that in UAS. Leading UAS manufacturers include a piloting program that can also livestream UAS feed on an internet network. Of these, the Skydio system is well regarded and can also be used to manage and track UAS fleets. The Fotokite system is also well regarded and allows streams to be shared via a URL. When the native app is not feasible, many DOTs use conference calls to stream UAS data. By connecting the UAS as a camera, the video is shared almost incidentally. However, conference calls can have serious lags or buffers when internet connection is poor. The next step is usually to use third-party streaming software. Services used in the State of the Practice include DroneSense, Responder Cast, and Airdata UAV. Summaries included in Table 5.2 were compiled using information found online and should not be the final determination for selecting software. It should be noted that pricing for the software providers was not included in the table as the companies offer individual quotes depending on integration needs.

DroneSense is a strong provider of livestreaming software and also includes fleet management capabilities and simple data sharing. However, DroneSense has largely been an iOS and DJI-compatible company. It has been expanding to Android and other UAS, but slowly. Another competitor is Airdata UAV, which provides data sharing and fleet management, but there are some concerns about security and reliable UAS compatibility. Responder Cast is also a streaming provider with a smaller service and may be less versatile. Acquiring third-party software is recommended when operating a DJI drone to minimize security concerns. Some DOTs also pursue in-house solutions, where UAS are connected to agency networks for quick sharing. However, creating those solutions requires technical expertise and long-term knowledge transfer. It can also be expensive to create the system and add UAS to the network.

5.2.4 Implemented Internet Connection Services

Connecting to the internet can be a serious limitation to streaming UAS data. Most DOTs utilize mobile internet connections but are beginning to transition to secure mobile solutions. Two common solutions are Verizon's Frontline and AT&T-based FirstNet. Both networks are well used and have different service networks and strengths. In Utah, AT&T might be better suited with better coverage. However, both networks struggle in remote regions and during high traffic events. In those scenarios, satellite internet may be preferred. Most DOTs using satellite internet acquire Starlink, providing high-quality internet across the U.S. and being highly portable. There are other solutions, such as HughesNet or Viasat, as mentioned in Table 5.3, but these are less portable and typically have data caps on their service.

If a consistently reliable and secure network is needed, a hybrid cellular network with satellite may be preferred. If most of the organization's working area has functional cellular coverage, then satellite coverage likely is not necessary. Additionally, with security, the more layers added provide better protection but also increase deployment complexity. As operators have limited time to manage these challenges, organizations should work to minimize complexity to improve functionality in the field.

5.3 Limitations and Challenges

The researchers faced several limitations and challenges when conducting the State of the Practice and compiling the report. Exploring these elements adds context to the findings in this report and acknowledges limitations to the widespread application of these findings. This section will summarize some of the limitations and challenges encountered during the study.

The first limitation of the research is a limited sample during the State of the Practice. As described in Section 3.2, the research team connected with various state DOTs and public organizations through online forums, mutual connections, and other online resources. At the end of each interview, the research team asked the organization's representative if they knew of other organizations for additional information. The research team sought to open communications with organizations that are industry leaders and those that have applied lessons from industry. Of the possible 50 state DOTs and limitless other state agencies, only ten state DOTs and one state DPS agency were interviewed, meaning there are likely other methods used in practice that this report does not cover.

A survey of the entire population of UAS implementing agencies, particularly those utilizing UAS livestreams, was not practical, but a 20 percent survey of DOT practices is a reasonable sample size. Statistical inferences on this data are not advised as DOTs were not selected randomly by the researchers. Additionally, not every DOT actively uses UAS for TIM or for livestreams. Some DOTs were not interviewed given their limited applicable experiences while other DOTs never responded to the inquiries of the research team.

A desired practice among DOTs is to regularly coordinate with other state DOTs to increase the flow of information. Evident among every DOT and agency interviewed or contacted was a general desire to improve collaboration to improve general practices. Contrasting with private practice, DOTs typically are not in competition with each other, and sharing best practices will only help improve safety and efficiency across all organizations.

In addition to a limited sample size, the interviews conducted by the research team only included a handful of representatives from each organization. When possible, the research team tried to contact program managers or team leads. While this was effective in gathering general information about specific programs, it potentially missed information that could be gathered from other team members. This includes, but is not limited to, specific technical information from front-line responders, technology personnel, and data security specialists. Additionally, many DOTs implement UAS policy across multiple departments. Interviewers attempted to find general practices among each DOT, but in some instances, findings were limited to specific departments or teams.

Due to the ever-changing nature of technology, regulations, and organizational practices, this report becomes less relevant the longer past publication. Aware of this challenge, the research team intentionally drafted the report to reflect common practices rather than focusing on specific software, brands, or networks that may become irrelevant. Public policy and legal requirements for use of UAS in a public safety context are also constantly in flux. This report focuses on national policy concerns with the security of DJI brand drones and other UAS operation requirements at or near the time of publication. This discussion is especially relevant at the time of publication as many DOT UAS fleets were primarily comprised of UAS manufactured by DJI. It is anticipated that as UAS technologies become more ubiquitous, public policy will evolve. This report recommends that all DOTs using UAS platforms to livestream for TIM regularly ensure their program fulfills legal requirements and that all practices and standards are regularly updated.

UDOT contracted with BYU Department of Civil and Construction Engineering researchers to complete this research. The researchers acknowledge that the bulk of their technical training primarily concerns roadway traffic operations, planning, design, and safety. Civil and Construction Engineering researchers have minimal technical training or expertise in other fields, including mechanical engineering, information sciences, cybersecurity, and legal or judicial training. Researchers intensely explored elements discussed in this report. Any errors are their own and should not reflect UDOT’s or BYU’s broad technical expertise. In-depth technical research with UAS and internet providers should be developed with department governing bodies before any solutions are purchased and implemented to ensure compliance with department and agency regulations and needs.

The technical solutions and the principals behind them provide a valuable ability to livestream UAS during incident management scenarios. While a restricted study size and other limitations may require additional vetting of potential solutions, doing so does not restrict the applicability of this research. Instead, using the principles provided, policy developers and UAS operators have the freedom to select a variety of technologies that may not be described.

5.4 Summary

UAV livestreams can address many challenges in traffic operations and emergency incident management. A UAV at an elevated position can be used to gather traffic data or to quickly convey the state of an incident to policymakers, response leaders, or the public. However, achieving this is often not a single solution process, requiring in-depth discussions to consider which technology may be most effective.

The three main components of UAS livestreams are the UAS, the streaming platform, and the internet connection. After creating a State of the Practice through interviews with various DOTs, commonly used solutions were identified and presented. When considering specific deployment needs and the key considerations for widespread use, a DOT is well equipped to integrate UAS livestreams into its traffic or incident management operations. Such implementation often occurs in phases to best apply this technology and to allow for specific implementation plans to shift in response to changing needs, technological capabilities, and adjusting federal and local regulations.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Introduction

Discussions with various DOTs and state agencies illustrated various implementation techniques or tools to integrate UAS with IMT or emergency response. The State of the Practice summarized these techniques and highlighted key concerns for UAS livestreams. Sharing UAS video data is feasible and can significantly benefit incident response. This chapter will first list several recommendations for future integration of UAS livestreams into incident response. Finally, an implementation plan will be provided for the research.

6.2 Recommendations

Based on the State-of-the-Practice findings, pursuing a UAS livestream program would be highly feasible and beneficial during select incidents; however, there are some limitations. FAA regulations requiring a visual line of sight between the UAS operator and the UAV limit effective livestream deployment by responding IMT forces. Having IMT members livestream incidents would likely reduce their ability to assist with scene recovery and clearing. However, in long-duration or high-severity-impact incidents, the benefits of UAS livestreams could outweigh these limitations.

This report recommends that UDOT utilize UAS that are not manufactured by DJI. Many DOTs have successfully integrated Skydio UAS into their fleets, but alternatives could be considered due to Skydio's higher price tag. Tethered UAS would also be highly beneficial during extended incident response and could be used in other capabilities, including traffic counts, origin-destination data collection, near-miss observations, or other traffic operation purposes.

Streaming UAS livestreams over conference call software is not recommended. Instead, UDOT should utilize internal streaming software specific to the UAV, avoiding national security concerns. Third-party software, including DronseSense and Airdata UAV, should also be considered. In-house solutions may be sufficient, but sharing outside the organization may be limited, particularly when sharing the data with state leaders or UHP. AT&T-based FirstNet internet should be largely sufficient for UDOT operators in Utah, Salt Lake, Davis, and Weber counties and in other larger urban areas. Coverage during high-traffic events or in canyons or more rural locations may be limited, and Starlink satellite internet (or similar providers) would be useful in these situations.

Integration of specific streaming and internet connection technologies should be considered after in-depth discussion with TOC operators to ensure compatibility with UDOT servers and security protocols. Additionally, due to frequent technological innovations and policy developments, decision-makers must be aware of changes in the UAS industry. Continual collaboration with other DOTs and UAS operators is a critical tool while developing a UAS program, and operators should attend conferences, workshops, and other events to collaborate with other operators and stay abreast of the most recent advances in the industry. In light of UDOT's successful integration of social media outreach into its operations, coverage of UDOT's UAS IMT implementation on social media could be a valuable outreach tool to strengthen public relations and provide useful information.

6.3 Implementation Plan

UDOT IMTs are in the process of replacing their DJI fleet with Autel UAS. Further research will be required to test different streaming services and Autel's ability to livestream UAS videos. UDOT IMT and the TOC are also applying to acquire a Fotokite tethered UAS for incident response and possibly for broader application use amongst other groups in the UDOT Traffic Management Division. It is expected that acquired Fotokite UAS will primarily be operated by IMT supervisors or other non-responding personnel. Further research could be pursued to test how UAS livestreams could be analyzed in real-time to collect traffic data to better respond to incidents. The benefits and limitations of integrating UAS livestreams with TIM operators should also be researched.

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