New England Transportation Consortium (NETC)

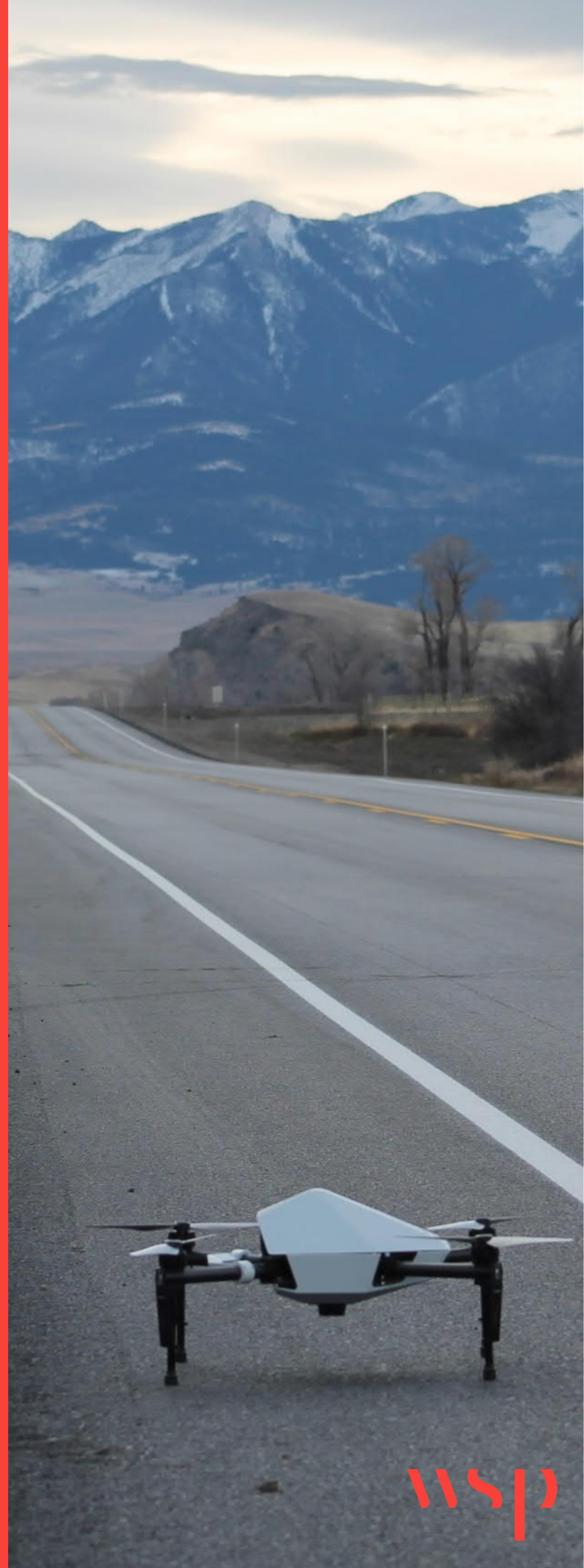
NETC 18-3

Integration of Unmanned Aircraft Systems (UAS) into Operations Conducted by New England Departments of Transportation

Task 3 Report

Challenges Associated with UAS Technologies, FAA Rules and Regulations

Revision dated October 7, 2020



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16. Abstract

Unmanned aircraft systems (UAS) technology is proving to enhance State Department of Transportation's (DOT) practices as an innovative and inexpensive solution that improves safety and accessibility, reduces cost, streamlines processes, improves workforce utilization, and accelerates several transportation operations activities. A few studies have been conducted at the national level, but little guidance has been published on incremental steps to integrating UAS in various applications. The objective of this research is to provide guidance to New England State DOTs regarding effective practices when incorporating UAS into daily operations. The third phase of this research, reflected in this Task 3 report, includes a systematic evaluation of Federal Aviation Administration regulations governing deployment of UAS for commercial transportation use cases and applicable waivers. Detailed process maps were developed for six use cases based on focused case studies conducted with UAS implementation at the New England State DOTs. Implementation challenges were also identified under three key areas—technological, operational (including managerial issues), and regulatory—and potential recommendations on mitigating these challenges are presented in this report. Subsequent phases of the research will develop detailed implementation plans for the selected transportation applications focusing on the current program maturity at the New England State DOTs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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1.0 INTRODUCTION

The objective of Task 3 is to design and conduct studies on specific transportation applications and the associated challenges that New England State Departments of Transportation (DOTs) encounter when deploying unmanned aircraft systems (UAS).[1] Table 1-1 lists the use cases assigned to each New England State DOT for further investigation regarding the challenges related to UAS deployment.

Table 1-1. New England State DOTs use cases for investigation.

New England State DOT	Use Case
Connecticut DOT	Construction inspection
Maine DOT	Bridge inspection
Massachusetts DOT (MassDOT)	Traffic monitoring
New Hampshire DOT	Surveying and mapping for highway design
Rhode Island DOT	Public engagement and outreach
Vermont Agency of Transportation (VTrans)	Emergency response and recovery

Working closely with the Project's Technical Advisory Committee, the research team identified the interviewees for case studies based on their knowledge of the UAS program and work experience in the chosen use cases. The team prepared an interview guide to facilitate the discussion based on the following topics:

- Programming and planning activities related to UAS operations.
- Resource allocation for UAS missions for the use case.
- Data collection and decision making.
- Challenges and perspectives using UAS.

The research team conducted phone interviews with each of the six teams about the six use cases. The case studies provided detailed procedural insights into the three stages of UAS operations—pre-flight planning, flight operations for data collection, and data post-processing. Key activities in the operational workflow were used to develop "process maps" specific to each use case. The research team considered the current status of the UAS program and the application-specific guidelines available at the New England State DOTs during the development of these process maps. Using the knowledge gained about the operational workflow through the case studies, the team identified several challenges for UAS operations and grouped them into four categories: technological/systematic, procedural/operational, regulatory/policy, and organizational. Mitigation strategies to alleviate the adverse impacts of these challenges were also identified based on the collective experience of the New England DOTs in using UAS and input from subject matter experts at WSP USA Inc. who specialize in geospatial technologies for surveying and data collection.

Additionally, the report also synthesizes effective practices applicable to all use cases based on industry research and a review of academic guidelines on UAS applications. These effective practices are intended

[1] For the purpose of the document, the term Unmanned Aerial Systems refers to small Unmanned Aerial Systems(sUAS) as defined under the Federal Aviation Administration's 2016 circular "*AC 107-2: Small Unmanned Aircraft Systems (sUAS).*"

to serve as a reference guide, particularly for those State DOTs whose UAS programs are nascent. Consideration of these practices during programmatic development could help DOTs avoid the specific use challenges highlighted in this study .

The rest of the report is structured as follows:

Section 2 provides an overview of the key Federal Aviation Administration (FAA) regulations that influence operating UAS for commercial operations and provides an assessment of Part 107 waivers available to abate the regulatory challenges that could arise when deploying UAS for several transportation use cases. FAA's recommendations for proposed approaches for demonstrating safe operations and enhancing the chances of approvals for Part 107 waiver applications are also documented. This section also includes details regarding the Low Altitude Authorization and Notification Capability (LAANC) request and authorization process used to gain access into controlled airspace near airports.

Section 3 describes the detailed findings from the six use case studies. Supported by case study interviews, this section details the operational workflow related to UAS deployment for the six use cases. Section 3 also highlights implementation challenges likely to occur when using UAS for accomplishing the mission objectives and proposes mitigation strategies to overcome them.

Section 4 focuses on the universal best practices for UAS operations based on findings from the review of industry best practices. This section covers topic areas such as organizational structure, mission planning and documentation, safety management and operational risk assessment, crew selection competences and training framework, data management, policies, and operations models. The insights from this chapter can assist State DOTs with nascent UAS program to overcome some of the initial institutional and procedural challenges with UAS deployment.

2.0 FEDERAL AVIATION ADMINISTRATION RULES AND REGULATIONS FOR USE CASES

Complying with flying requirements for UAS and obtaining necessary approval or waivers from regulatory authorities is a common requirement for UAS deployment for various transportation use cases. The relevant rules and regulations for UAS operations are those enacted by the various levels of government including Federal, State, local, county, city, and township, with Federal regulations generally overriding the requirements from State and other local entities with respect to the UAS.

The primary federal regulation influencing non-hobby UAS operations is the FAA Small UAS Rule (Part 107), enacted on August 29, 2016. Figure 2-1 summarizes the FAA framework for regulations for UAS, including Part 107 and alternative options available for seeking approvals. The framework is summarized below according to the latest FAA guidelines (Federal Aviation Administration, 2020b).

- If the weight of the aircraft remains less than 55 pounds and there are no special needs such as transportation of packages (including hazardous materials and manned missions), 14 Code of Federal Regulations (CFR) Part 107 Guidelines govern the approval procedures for mission. Procedures to obtain necessary waivers are covered later in this section.
- If a UAS weighs more than 55 pounds, FAA recommends operators apply for exemption under Special Authority for Certain Unmanned Systems (49 United States Code [U.S.C.] §44807). This route is usually sought for package delivery, including hazardous materials. It is worth noting that the 2018 FAA Reauthorization Act repealed Section 333 and introduced Section 44807 to replace it.
- If a mission involves complex UAS systems and has complex objectives (including manned missions), traditional certification procedures must be followed as stated in 14 CFR Part 21 for design of aircraft and its components (Type Certification), scaling up the production for manufacturer (Production Certification), and verifying its safe operational condition for stated mission (Airworthiness Certification).

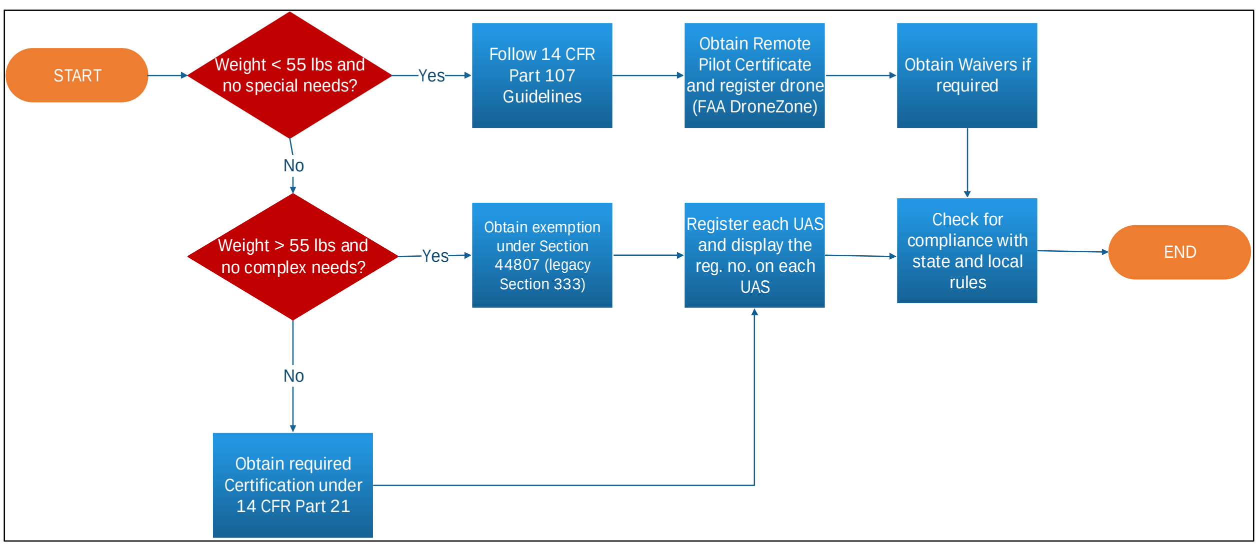


Figure 2-1. Illustration. Framework for FAA regulations for unmanned aerial systems.

Part 107 simplified requirements for flying UAS by eliminating the need for airworthiness certification mandated under pilot certification requirements under 14 CFR 61 (Part 61). For other unmanned missions with aircraft weighing more than 55 pounds, the Secretary of Transportation can provide exemptions on case-by-case basis to the applicable operating rules and aircraft and pilot requirements to ensure safe integration into operational airspace. Any other aircraft must go through the conventional certification process to obtain necessary approvals. Both Part 107 and Part 21 missions must comply with airspace requirements or obtain a waiver/certificate of authorization (COA) to fly beyond requirements. Because the focus of this study pertains to small unmanned aerial systems (sUAS) that are commonly used in transportation applications by State agencies, the regulatory processes corresponding to this pathway is explored in detail.

2.1 Federal Aviation Administration Part 107 Waivers

FAA evaluates applications for waivers and COAs to deviate from some of the Part 107 rules on a case-by-case basis. To date, the most commonly granted waivers (with adequate representation from State DOTs) pertain to §107.29 (Daytime Operations) and §107.41 (Operations in Certain Airspace) (Banks et al., 2018). Iowa DOT was issued 18 waivers between November 2016 and May 2017 for Part 107.41. Georgia DOT was issued a waiver for Part 107.29, effective March 13, 2017, with some special provisions to ensure safe operations at night (illumination, visual observer [VO] presence, and anti-collision lighting for UAS). A recent survey by the Eno Center for Transportation reported that night operations remain the largest category of waiver applied for and granted by FAA, although a considerable number of requests have been made for waivers under other categories especially for Operations Over People and Beyond Visual Line of Sight. The large number of approvals for waivers permitting night operations is largely attributed to better understanding of hazards and risk mitigation strategies by FAA (Dunlap & Paul, 2020). On an average, it required around 40 hours to prepare and submit a waiver application. The study also concluded that most of the waivers were approved within 60 days or less.

FAA has systematically laid out the approach to request a waiver for various operations. The process begins with identifying the mission timeline and objectives and designating a responsible party for whom the waiver will be designated. The responsible party is in charge of safely conducting the operations, maintaining the details of aircraft and pilots, and ensuring compliance with the regulations and approved waivers. A Remote Pilot in Command (RPIC) should also be identified, if separate from the responsible party. All of these details are submitted in the application on FAA's DroneZone portal. The applicant must also explain in detail the safety protocols being put in place to ensure operational smoothness and safe performance of the flight for each regulation being waived. FAA communicates the decision within approximately three months—this time period may also involve requests for additional information and instructions to make additional submissions.

Table 2-1 presents the FAA waivers potentially required for various transportation use cases. The designations of waivers for use cases presented are provided based on anticipated conditions for UAS deployment for the particular use case—they do not represent definitive requirements, and actual requirements may vary depending on site conditions and other operational circumstances that may arise during the UAS operations.

Table 2-1 Potential FAA Part 107 waiver requirements for transportation use cases.

	Transportation Use Cases					
Potential Waivers from FAA Rule	Bridge Inspection	Emergency Response	Public Outreach and Engagement	Construction Inspection	Traffic Monitoring	Surveying and Mapping
§ 107.25 – Operation from a Moving Vehicle or Aircraft	✓					
§ 107.29 – Daylight Operations	✓	✓		✓	✓	✓
§ 107.31 – Visual Line of Sight Aircraft Operation	✓	✓		✓		✓
§ 107.33 – Visual Observer	✓	✓		✓		
§ 107.35 – Operation of Multiple Small UAS	✓	✓		✓	✓	✓
§ 107.37(a) – Yielding Right of Way						
§ 107.39 – Operation Over People		✓	✓		✓	✓
§ 107.41 – Operations in Certain Airspace (Class B, C, D, or E)	✓	✓		✓	✓	✓
§ 107.51 – Operating Limitations for Small Unmanned Aircraft		✓			✓	✓

Note: A "✓" mark indicates a waiver may be required for deploying UAS for the particular transportation use cases.

As shown in Table 2-1, many transportation use cases may require obtaining an FAA Part 107 waiver depending on the site conditions and operational constraints. In particular, UAS deployment for emergency response may require operating the system under extreme conditions and often need expedited approval of waivers. FAA provides special consideration for expedited approval for UAS deployment for emergency response through Special Governmental Interest (SGI) protocols. An applicant with an existing RPIC certificate can submit an Emergency Operations Request Form (EORF) to FAA's System

Operations Support Center (Federal Aviation Administration, 2020a) and request expedited approval for their mission. Many State agencies such as VTrans have developed detailed guidelines for expedited approval for emergency response missions.

FAA also compiled UAS operational data from Part 107 waiver applications submitted thus far and provided additional guidance on key information or approaches proposed by applicants that enhanced their chances for approval (Federal Aviation Administration, 2020c). FAA stressed the need to detail the operational risk assessment and countermeasures proposed to mitigate the risks to ensure a high chance of approval in the process. Proposed recommendations for three Part 107 waivers are summarized in Table 2-2.

Table 2-2 Recommendations for approaches to FAA Part 107 waiver applications.

Requested Waiver	Proposed Approach	Description
Beyond Visual Line of Sight (107.31)	Command and control (C2) link and emitters performance capabilities	Clearly stating the C2 limits of the chosen sUAS platform and enumerating the spectrum details of the emitter/transmitter on the sUAS and ground control points (GCPs) (Note: *The C2 link between UAS and RPIC provides vital information on operational parameters such as climb rate, turn rate, altitude, position, and speed to help the pilot ensure safe missions and regulatory compliance*). The four modes of C2 governing the extent of pilot control include direct control, mode control, flight plan control, and autonomous control. These parameters are further explained in Task 2 report.
	Detect-and-avoid methods	Documenting the approaches to detect collision hazards and avoid them (methods include engaging a VO, and sensors (Stereo Vision, Monocular Vision, Ultrasonic, Infrared, Time-of-Flight or LiDAR-based) for detecting obstructions and collision avoidance).
	Weather tracking and operational limitations	Adequately documenting weather conditions on-site and implications on operational limits of the chosen sUAS platform.
	Special training of RPIC and the crew	Highlighting the training and credentials of the pilots and their flight hours along with topics covered that would help in operating beyond visual line of sight or BVLOS.
Operations Over People (107.39(a))	Ground collision severity, laceration injuries and mitigation strategies	Detailing the impact and severity of potential injuries from the chosen sUAS (own tests or manufacturer provided) and identification of mitigation strategies (such as

Requested Waiver	Proposed Approach	Description
		parachutes deployment) to minimize impact
	Operational details	Documenting operational limitations for chosen UAS and site conditions (altitude, wind speed, area of operation, temperature range), and contingency actions for system failures (Return to Home Mode).
	Qualifications and experience of RPIC for the specific waiver/case	Highlighting the flight training and site training of RPIC in safely operating the chosen sUAS on similar working conditions; providing the hours of experience of similar flights.
Night Operations (107.29)	Maintain situational awareness and communication between RPIC, VO, and sUAS	Adding lighting method to ensure visibility of sUAS for at least 3 miles and deploying a VO with appropriate communication protocol with RPIC to provide needed update on UAS operations; it is also recommended to include procedure to be followed if there is loss of sight during nighttime operations
	See-and-avoid methods	Including detailed description of methods to detect and avoid other aircrafts (particularly with training) and avoid potential conflicts with ground-based structures and other non-participants.
	Qualifications and experience of RPIC for the specific waiver/case	Highlighting the flight training and site training of RPIC in safely operating the chosen sUAS on similar working conditions; providing the details and records of the hours of experience of similar flights.

Source: Adapted from (Federal Aviation Administration, 2020c).

2.2 Low Altitude Authorization and Notification Capability

Operating a UAS in certain airspaces closer to airports may be necessary for some transportation applications (such as performing bridge inspection or traffic monitoring near airports). Detection of these technologies in airport environments presents operational challenges for civil use. Nonetheless, FAA rolled out a beta version of its Low Altitude Authorization and Notification Capability (LAANC) in September 2018 at about 400 air traffic controls covering 600 airports to enable UAS operators to automate the authorization of airspace near airports (Federal Aviation Administration, 2019). LAANC expedites the application and approval process making it real-time through automated exchange of airspace data between FAA and approved UAS Service Suppliers. Approval is granted by validating the request against multiple data sources, including UAS Facility Maps, Temporary Flight Restrictions, and Notices to Airmen. Part 107 operators must review the information in UAS facility maps regarding the pre-approved zones and altitudes and understand the Temporary Flight Restrictions in place through the

FAA's DroneZone before requesting LAANC approvals. FAA's B4UFLY application can also be used to check airspace before taking flight to ensure compliance and safe integration with national airspace.

Many commercial flight planning software products have integrated capabilities that enable drone operators to request digital airspace authorization in controlled airspace for a variety of missions. If operators need to fly outside pre-approved zones and altitudes near airports (as shown in UAS Facility Maps) or if they need controlled airspace access near airports not offering LAANC, the flights have to be manually authorized by Air Traffic Control and coordinated through FAA at least 90 days prior to the mission. Figure 2-2 summarizes the workflow involved in the LAANC request and authorization processes.

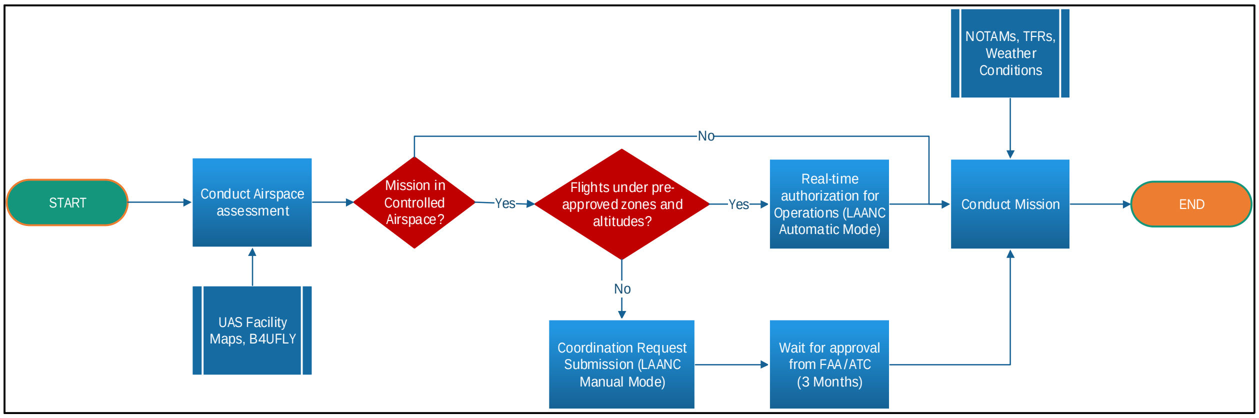


Figure 2-2. Illustration. LAANC request and authorization workflow.

2.3 State and Local Regulations

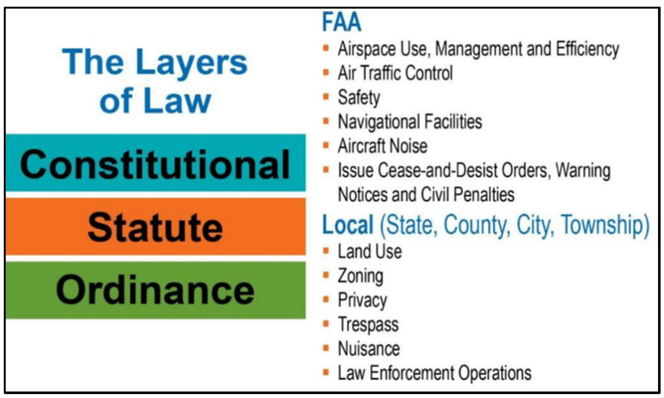
Most states also have some legislation that affects UAS operations. Table 2-3 details select UAS laws at the State level for the New England states as of 2017. This list is for informational purposes only and is meant to illustrate actions taken by relevant State legislatures to enable or restrict the use of UAS. Other rules/regulations may exist.

Table 2-3. New England state UAS laws.

State	Reference	Comments
Connecticut	Public Act 17-52 (2017)	Restricting ratification/enforcement of municipal rules unless authorized by state/federal law without conflict of Connecticut Airport Authority (Rupprecht Law P.A., 2017e).
Maine	Maine Revised Statutes Title 25 §4501 (2015)	Regulations, provisions, and minimum standards for use of UAS by a law enforcement agency (Rupprecht Law P.A., 2017a).
Massachusetts	None	Judge in Singer v. City of Newton case ruled (conflict preempted) against including provisions to local ordinances related to UAS registration, complete UAS bans, regulating navigable airspace, and limiting "the methods of piloting a drone beyond that which the FAA has already designated" (Rupprecht Law P.A., 2017b).

State	Reference	Comments
New Hampshire	Title XVIII §207:57 (2016)	Restricting the use of UAS for surveilling private citizens who are lawfully hunting/fishing (not applicable to a law enforcement agency) (Rupprecht Law P.A., 2017c).
Rhode Island	Title 1 §1-8-1 (2016)	State of Rhode Island and the Rhode Island Airport Corporation has exclusive legal authority to regulate UAS (subject to FAA) (Rupprecht Law P.A., 2017d).
Vermont	Title 20 Chapter 205 (2018)	Restricting the use of UAS by a law enforcement agency for investigating, detecting, or prosecuting crime (other noted uses are allowed). FAA requirements and guidelines are to be followed for use of UAS (State of Vermont, n.d.).

Local regulations from States and counties usually focus on aspects that relate to law enforcement and other issues concerning safe and successful UAS operations for the State (Figure 2-3). FAA regulations supersede them in the order of priority.



Source : (Mallela et al., 2018).

Figure 2-3. Illustration. Order of legislative influences for UAS operations State.

3.0 PROCESS MAPPING FOR USE CASES AND SPECIFIC IMPLEMENTATION CHALLENGES

While UAS offer significant benefits for data collection to support various use cases, understanding the general circumstances that would warrant investing or deploying the technology against a wide array of other data collection technologies is important. To comply with quality control (QC) considerations, it may be necessary to integrate UAS data with other geospatial tool such as LiDAR, Global Navigation Satellite System (GNSS) rovers, total stations, and closed-circuit television cameras among others. Accuracy and resolution are often the benchmarks used to evaluate the quality of the data collected using these technologies. High network survey accuracy can obviate expensive redesign and change orders at the expense of increased cost for data collection and processing. Similarly, high image resolution or point cloud density can include adequate detail of the elements being surveyed at the expense of increased cost (Mallela et al., 2018). © 2015 Michael Olsen and Dan Gillins.

Figure 3-1 demonstrates the achievable spatial resolution and accuracy of geospatial technologies. The number of spatial dimensions in this figure is indicated by blue (one-dimensional – elevation only), red (two-dimensional – coordinates only), and black (three-dimensional [3D] – elevation and coordinates) text. This figure can facilitate the decision-making process to select the appropriate technology based on the accuracy and resolution requirements for a specific application (Olsen & Gillins, 2015).

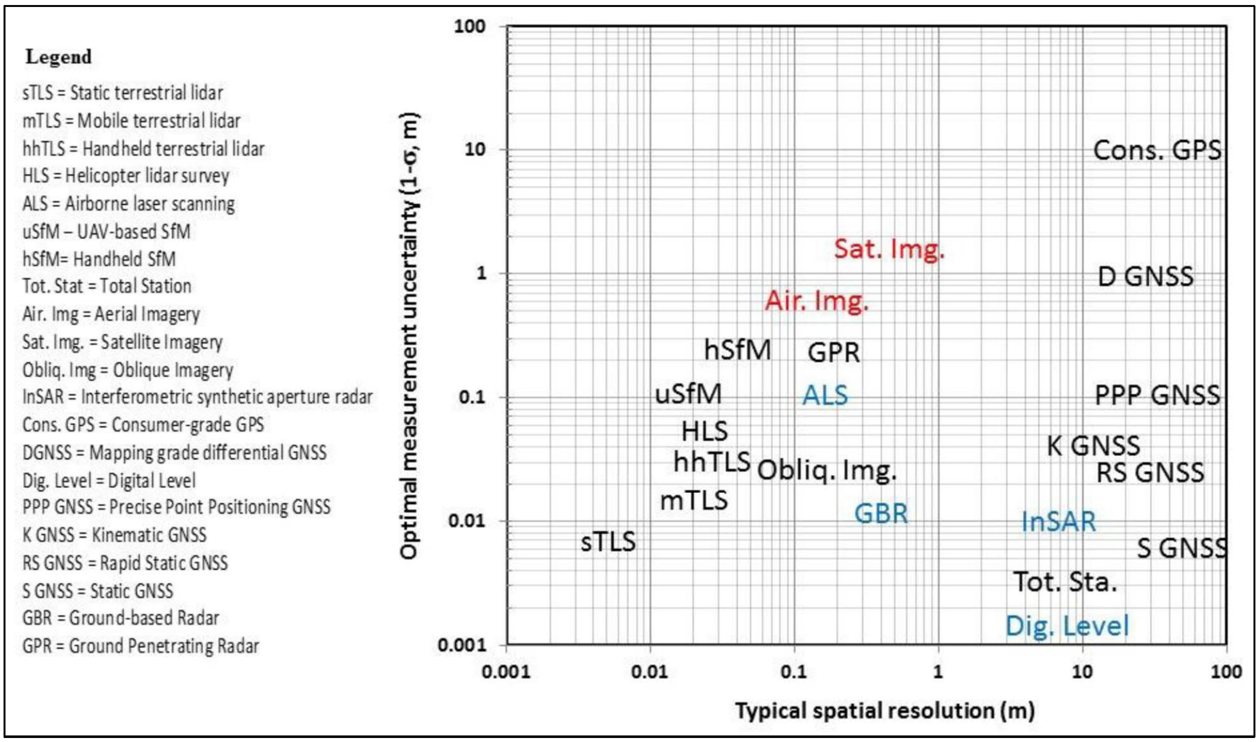


Figure 3-1. Graph. Accuracy and spatial resolution capabilities of typical geospatial tools.

UAS technology is best suited for projects that require moderate spatial resolution and where some level of measurement uncertainty is acceptable. However, the technological capabilities of UAS have significantly improved over the past few years, and sensor payloads (e.g., RGB cameras and LiDAR sensors) are becoming more cost effective. As the technology evolves to meet accuracy requirements and becomes more cost effective, its usage for transportation applications will become more widespread, enabling improved spatial resolution with less measurement uncertainty.

When UAS are deployed for transportation applications, investments are generally made in the development and adoption of UAS operation manuals and policies and key specifications that guide evaluation of survey products. Common performance specifications when analyzing collected data for QC for transportation applications include spatial resolution, point density, horizontal and vertical accuracy (HA, VA), ground sample distance (GSD), and camera shutter type, among others. Table 3-1 enumerates the typical specifications of the UAS platform and sensor payloads for various transportation use cases. These values are consolidated based on the analysis of the literature and experience of the research team in conducting UAS operations to support various missions.

Table 3-1. Common transportation use case specifications for UAS deployment.

Use Case	Airframe Type	Flight Duration	Data Type	Shutter Type	Point Density/ Spacing[1]	Minimum GSD	Horizontal Accuracy Class[2]	Vertical Accuracy Class[3]
Bridge Inspection	Multi-copter	> 45 min.	Imagery and Video	Global	N/A	1 cm	1.25 cm	5 cm
Traffic Monitoring	Multi-copter	> 45 min.	Video	Any	N/A	5 cm	N/A	N/A
Public Outreach and Engagement	Fixed wing	> 45 min.	Imagery, Video, 3D Mesh	Any	N/A	5 cm	N/A	N/A
Emergency Incident Response	Fixed-wing[4]/ Vertical Take-Off and Landing (VTOL) (linear assessment); multi-copter (structural)	> 45 min.	Imagery and Video	Any	N/A	1 cm	1.25 cm	2.5 cm
Construction Inspection	Any (depending on project size and complexity of traffic control)	> 30 min.	Imagery, LiDAR, Planimetrics, Surface Model	Global	16/0.25	0.5–5cm	2.5–5cm	2.5–5cm
Surveying and Mapping	Multi-copter	> 45 min.	Imagery, Video, LiDAR, Planimetrics, and Surface Model	Global	≥20/≤0.22	0.5 cm	0.63 cm	1 cm

1 LiDAR-only datasets. Only for non-vegetation area of interest point density in points per square (pts/m^2); point spacing in meters (m).
2 Horizontal accuracy class as defined in ASPRS Positional Accuracy Standards for Digital Geospatial Data.
3 Vertical accuracy class as defined in ASPRS Positional Accuracy Standards for Digital Geospatial Data.
4 If clear takeoff and landing zone is well defined and reliable for duration of flight.

Typically, UAS deployment procedures for any application consist of planning activities that occur in office settings where mission details and resourcing the mission with required crew and systems are discussed. The crew then mobilizes the site and carries out certain pre-operational checks to verify planned parameters and capture and plan for any potential uncertainties that could arise in the field. Once this stage is complete, data collection is carried out using standard operational considerations of the agency and best practices that consider QC and safety. The collected data are then processed using appropriate software to produce final deliverables. In general, the process of UAS deployment consists of three distinct stages—pre-flight planning, flight operations and data collection, and post-processing. These three stages are often customized, depending on the specific use case and the procedural requirements of a particular agency. The subsequent sections detail process mapping for individual UAS use cases and identify implementation challenges and mitigation strategies learned from case studies conducted as part of Task 3.

The challenges identified for each of the six use cases are also mapped to the three stages of UAS operations and given the following three gradations based on their level of applicability and impact on the stages of UAS operations:

- Low: The challenge only marginally applies to the pertinent stage of UAS operations. The level of impact is minimal on the efficiency of UAS operations for this stage. Developing mitigation strategies to address this challenge is optional (subject to leadership intent and availability of resources).
- Medium: The challenge has a considerable impact on the applicable stage for UAS operations. The level of impact is moderate, and it is recommended that the agency develop solutions to mitigate the adverse impact of the issue on safe and efficient UAS operations.
- High: The impact of the challenge on the applicable stage is significant, and it is strongly recommended that the agency develop mitigations strategies to alleviate the adverse impact of the issue on UAS workflow.

3.1 Bridge Inspection (Maine DOT)

Periodic inspection of bridges per National Bridge Inspection Standards is important for Maine DOT to ensure the State of Good Repair and identify and prioritize necessary maintenance and rehabilitation projects. UAS technology can play an integral role in routine inspection given the technological capabilities of the sensor payloads and advancements made in software and support systems for flight planning, data collection, and analysis. Evidence exists in both literature and practice supporting UAS usage with regard to enhanced safety, improved productivity, and quality confirming to specification requirements of DOT inspection manuals and National Bridge Inspection standards.

Task 1 explored the operational profile of Maine DOT in terms of its current UAS capabilities and identified deploying UAS for bridge inspection as a key area of interest. Task 2 documented the criteria for key technologies and systems requirements to consider for using UAS for bridge inspection and enlisted market-ready products available for immediate usage. Based on the findings from Tasks 1 and 2 and an interview conducted with the bridge inspection group from Maine DOT, this section enumerates the challenges involved in integrating UAS for bridge inspection and suggests potential mitigation strategies to address some of the challenges.

3.1.1 Stages of UAS Operations for Bridge Inspection

To facilitate the process of analyzing the challenges and developing recommendations, a consistent workflow of UAS operations is maintained across all the use cases. The process workflow for using UAS for bridge inspection is divided into three stages—pre-flight planning, flight operation and data collection, and pre-processing of results. Appendix A-1 includes a graphical depiction of the process of bridge inspection.

3.1.1.1 Pre-flight Planning

This stage comprises the planning activities required for evaluation in office and field environments to ensure safe operations of the flight when deployed for bridge inspection. The process involves a clear understanding of the scope and objectives of the bridge inspection task and the data requirements that inform selecting appropriate systems and staffing needs. System selection involves choosing efficient aircraft platforms (VTOL), identifying sensor payloads (RGB cameras/infrared/LiDAR), and additional considerations especially if the inspection involves confined spaces. Maine DOT's bridge inspection manuals and its UAS policy for operations should be considered while preparing for any mission. The agency's inspection manual recommends inspecting individual elements of substructure, superstructure, and deck and determining their condition states. Sensor payloads should be chosen to support the level of detail required to accomplish this objective. Any additional waivers required for FAA's Part 107 regulations must be obtained.

A robust flight plan should be supplemented with a site survey of the bridge inspection site to prepare for anticipated wind speed, precipitation, temperature, humidity, and altitude of operations. Field conditions can influence the selection of appropriate platform, payloads, and experienced personnel. The agency's UAS Program Coordinator should use the results from the overall evaluation to make a go/no-go decision for the process to move to flight operations.

3.1.1.2 Flight Operations and Data Collection

This stage involves the primarily on-site processes to collect the data required for assessing the conditions of various elements during a routine bridge inspection, including identifying the crew to be deployed (in-house personnel or the UAS consultant responsible for UAS operations). At a minimum, the crew should include an RPIC and a VO who meet the FAA training requirements and are familiar with UAS operations and Maine DOT policies. If required, an additional agency representative should be available on-site to supervise UAS operations. Once the crew deployment is complete, various preparatory activities for system set-up can be performed, including establishing ground control points (GCPs) (with or without real-time kinematics [RTK]), assessing weather in the field, and ensuring necessary checks for communication using remote control under various scenarios for inspecting elements. Before take-off, the UAS team should consider the following situations that can influence the success of the mission for bridge inspection:

- Potential for magnetic interference of UAS components especially when deployed for steel structures. This issue largely affects pre-takeoff compass calibration and telemetry signal transmission, especially when the pilot and aircraft are situated on the bridge deck.
- Potential chances for operational failure due to upward collision with structural elements. To prevent this, the system should be equipped with upward obstruction sensors.
- The potential for atmospheric wind shear, such as vertical and horizontal vortexes, that can cause sudden movements during the operation. Smaller aerial platforms are susceptible to small changes and critical system failure by collision.

The RPIC performs a final authorization of the operation after considering all the preparatory activities. During operations, the key technical parameters of the mission, such as altitude, speed, communication checks, battery performance (or power), must be monitored continuously and comply with data requirements. Element-level inspection of bridges may require multiple flights, depending on battery life, weather conditions, and level of detail requirements for each element. Special attention should be given to:

- Safety and training especially when deploying UAS for inspecting confined spaces.
- Stability and sturdiness of the platform in adverse weather conditions (e.g., high winds).

A detailed list of UAS selection criteria is provided in the Task 2 report for bridge inspection.

Once the required data are collected, pre-landing checks must be carried out with clearance from VOs to ensure safe landing. Subsequently, post-flight checks are conducted, and the flight operation is logged with any notable incidents that occurred during the flight. The collected data can then be downloaded (using a flash drive or transferred to the office using VPN) and calibrated with required corrections to determine accurate sensor location using GCP/post-processing kinematics (PPK) techniques.

3.1.1.3 Post-processing

This stage involves processing collected data to assess the conditions of various elements of the bridge and to archive the records in the National Bridge Inspection database and in the agency's asset management system for future references and planning for maintenance and rehabilitation. Depending on the type of sensors used (RGB cameras/infrared/LiDAR), different types of pre-processing techniques can be deployed to analyze the images. Images can be processed using several commercial-off-the-shelf (COTS) platforms or using proprietary vendor software to determine required information on condition states (common defects include cracks, potholes, exposed rebars, ravels, and concrete delamination among others). Once processing is complete, the post-processed data can be archived according to the agency's digital data archival and retention guidelines.

3.1.2 Challenges and Recommendations

Darby and Gopu report that a comprehensive bridge inspection with the ability to identify and understand the existing conditions and functionalities of all the elements is challenging with several dynamic constraints (Darby & Gopu, 2018). Table 3-2 identifies the specific challenges for the bridge inspection use case during the three stages of UAS operations and groups them as technological, operational, or policy related. It also discusses applicable recommendations or mitigation strategies for agencies to overcome these challenges.

Table 3-2. Implementation challenges and potential recommendations for bridge inspection use case for Maine DOT.

Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operation	Post-processing	
Technological/ System	Rapidly evolving technological landscape and advancements in capabilities (e.g., sensor payloads, support systems and software for mission control, data collection and processing)	Medium	Low	High	Emphasize performance specifications and require necessary equipment from consultants. Specific criteria to consider for UAS selection for bridge inspection include adequate horizontal and vertical accuracy, stability against weather conditions, dexterity to manual operations, resistance to potential magnetic interference, and obstacle avoidance sensors.
	Obscure images or videos reducing quality of data due to challenging field conditions (lighting, inclement weather, and other objects obscuring sensors)	Low	Medium	High	Implement process to avoid adverse weather conditions and poor-quality data. Invest in data processing software that uses artificial intelligence (AI) and advanced image processing algorithms to address poor illumination or other occlusion in observed data.
	Limitations in flight planning software for inspections and environmental impacts (e.g., wind, climate) to safe, stable, and consistent flights	High	Medium	Low	Increase capacity of UAS pilots to plan their flights with these factors in mind to help mitigate software challenges.
Procedural/ Operational	Lack of standard operating procedures and safety policies or inadequate definitions of performance requirements for element-level bridge inspection	High	Medium	Low	Prepare and incorporate UAS performance criteria for bridge inspection use case in the agency's SOP manuals

Type	Description of the Challenge	Level of Applicability or Impact: Pre-flight Planning	Level of Applicability or Impact: Flight Operation	Level of Applicability or Impact: Post-processing	Recommendations
	Operation in confined spaces or access-constrained environments	Medium	High	Low	Train pilots to operate in access-constrained environments (ensuring appropriate initial and recurring training requirements for RPIC, VO, and other crew members).
					Invest in collision-tolerant drones (such as Flyability Elios) to inspect confined spaces such as beneath the deck of the bridge.
	Operational hazard to navigate UAS beneath the deck of the bridge due to intermittent or total loss of signal	Low	High	Low	Avoid inspections using UAS beneath the deck if safety hazard is high for the chosen structure.
					Implement multi-pilot operational method to take over the control of the aircraft when primary pilot loses the signal.
Regulatory/ Policy	Time constraints to obtaining required waivers for bridge inspection	High	Low	Low	For obtaining waiver, consider bundling multiple sites into an airspace map and obtain COAs for flights that establishes operational ceilings based on proximity to airports (e.g., MnDOT's airspace map).
					Consider LAANC for obtaining waiver to access controlled airspace near airports.

3.2 Emergency Response (VTrans)

According to the 2040 *Long Range Transportation Plan*, adoption of modern technologies to enhance safety and security across all transportation modes emerged as a key priority for VTrans along with assurance of the State of Good Repair of critical assets and improved mobility. With an established UAS program under its Rail and Aviation Bureau, the state manages UAS operations for several transportation applications, including emergency and incident response/recovery operations. UAS can provide invaluable assistance for emergency response and recovery during major natural disasters (e.g., flooding, landslides, avalanches, hurricanes, and wildfires, among others). The major objectives of these missions range from supporting rescue and rehabilitation efforts to damage assessment and reconnaissance survey.

Task 1 explored the operational profile of VTrans in terms of its current UAS capabilities and identified deploying UAS for emergency and incident response as a key area of interest. Task 2 documented the criteria for key technologies and systems requirements to consider for using UAS for emergency response and enlisted market-ready products available for immediate usage. Based on the findings from Tasks 1 and 2 and the interview conducted with VTrans' UAS and emergency response teams, this section enumerates the challenges involved in integrating UAS for emergency response and suggests potential mitigation strategies to address some of the challenges.

3.2.1 Stages of UAS Operations for Emergency and Incident Response

As noted above, a consistent workflow of UAS operations is maintained across all the use cases. The process workflow for using UAS for emergency response is divided into three stages—pre-flight planning, flight operation and data collection, and pre-processing of results. Appendix A-2 includes a graphical depiction of the process of emergency response.

3.2.1.1 Pre-flight Planning

This stage comprises planning activities required for evaluating office and field environments to ensure safe operations of the flight when deployed for emergency incidents and recovery. The process involves a clear understanding of the scope and objectives of the task and the data requirements that inform selecting appropriate systems and staffing needs. VTrans' emergency response guidelines and the UAS manual for operations should be considered while preparing for any mission. System selection involves choosing efficient aircraft platforms depending on emergency situations (fixed-wing aircrafts with more flight duration and stability considerations over VTOL platforms that are more agile), identifying sensor payloads (RGB cameras/infrared/LiDAR), and situational constraints that are unique for emergency response. Some of these considerations include:

- Requesting the mission through one of the four regional commands under the Incident Command System (ICS) and ensuring one of them is activated to support the mission. The ICS provides an organized hierarchy of command, control, and coordination for emergency response teams with stakeholders from multiple agencies.
- Leveraging the UAS Command and Control[2] approach through the Transportation Incident Command Center (TICC) for an expedited mission request and approval process to deploy UAS for emergency response. The C2 framework comprises three fundamental dimensions proposed by the U.S. Military—process, organization, and function—and is recommended for adaptation by other emergency response organizations (Chumer & Turoff, 2006).

[2] Note that the reference to C2 here is different from the UAS Command and Control data link between the remote pilot and the aircraft during flight operations.

- Process: The C2 process includes four major steps: (1) observing the situation and extracting the relevant information through appropriate sensing elements (visual, sound, tactile, scent, taste, vestibular, and kinesthetic data); (2) integrating the collected data using appropriate methods; (3) deciding appropriate actions based on orientation and communications with all actors; and (4) acting on the decision and continuous monitoring.
- Function: The C2 function includes both a physical organization that acts as a central command center on-site to respond to emergency situations (such as VTrans' TICC), as well as protocols for adding a virtual extension to bring in additional expertise from outside the center if the situation warrants it. The agency can also consider adding a redundant C2 or distributed C2 in case the physical C2 function becomes disabled or loses control over unexpected circumstances. In the VTrans case, one of the four regional commands can accomplish these objectives.
- Organization: The C2 as an organization promotes parallel communication and collaborative interpretation between various stakeholders so that the information sensed by the operational unit is translated to sensible and concerted actions. The military suggests two types of organizational structure for consideration: Network Centric Organization (NCO), High Reliability Organization (HRO), and conventional bureaucratic structure. Table 3-3 compares the salient features of the organization structures proposed by the military for emergency response.

Table 3-3 Comparison of different C2 organizational structures for emergency response.

Features	NCO	HRO	Bureaucracy
Hierarchy of Authority	Emerges from the network	Inverted structures often emerge	Traditional hierarchies
Rules and Procedures	Emerges from the network	Can be rigid or adaptable	Compartmentalized rigidity
Division of Labor and Specialization	Suggested by network	Often in federated structures	Rigid, often resembles smokestacks
System of Impartial Decision Making	Embedded in the network technology	Can be structured or adaptable (both human and technology based)	Often tightly structured and highly routinized
Employees Hired Impartially	Depends upon organization	Depends upon organization	Depends upon organization
Principles of Efficiency	Embedded in the network	Embedded in the organizational structure	Embedded in the organizational structure

Source: (Chumer & Turoff, 2006).

- Ensuring continuous communication between UAS mission planners and the tasking command throughout the pre-flight planning to:
  - Ensure C2 is fully understood as a process, organization, and function by all stakeholders.
  - Understand timelines of upcoming missions and resolve any technological challenges.

Any additional waivers required for FAA's Part 107 regulations must be obtained. A robust flight plan should also be supplemented with a site survey, hazard identification, and operational risk assessment for launching UAS for emergency response. FAA provides special consideration for expedited approval for

UAS deployment for emergency response through its SGI protocols. An applicant with an existing RPIC certificate can submit an EORF to FAA's System Operations Support Center (Federal Aviation Administration, 2020a) and request expedited approval for their mission. The field conditions can influence the selection of the appropriate platform, payloads, and experience of personnel. The agency's UAS Program Coordinator should use the results from the overall evaluation to make a go/no-go decision for the process to move to flight operations.

3.2.1.2 Flight Operations and Data Collection

This stage involves the mostly on-site processes to collect required data for assessing the conditions of various elements during emergency response operations. The crew involves in-house personnel or the UAS consultant responsible for UAS operations and, at a minimum, should include an RPIC and a VO who meet the FAA training requirements and are familiar with UAS operations and the emergency response guidelines for VTrans. If required, an additional agency representative should be available on-site to supervise UAS operations. The RPIC performs a final authorization of the operation after considering all the preparatory activities, including pre-flight checks on the field and hover testing. The crew should establish and maintain communications with the tasking command at the ICS throughout the mission to ensure adherence to mission timelines and objectives and to respond adequately to dynamic re-tasking over the damaged area during the mission.

During operations, the key technical parameters of the mission, including altitude, speed, communication checks, battery performance (or power), must be monitored continuously and comply with data requirements in accordance with the ICS. Operational requests for emergency response usually involve a broad area overflight to conduct damage assessment, and a live video feed is often requested (while post-processed products are also requested occasionally). Additional technological capabilities to consider include a wireless network for live transmission and real-time processing software solutions for analysis and relay of required imageries/videos. After the mission is completed, post-flight checks are conducted, and the flight operation is logged with any notable incidents that occurred during the flight. The collected data are then downloaded (using a flash drive or transferred to office using VPN) if post-processed products are necessary.

3.2.1.3 Post-processing

This stage involves processing the collected data using various image processing or photogrammetric solutions to generate the required outputs. Depending on the type of sensors used (RGB cameras/infrared/LiDAR), different types of processing techniques can be deployed to analyze the data. Data can be processed using several COTS platforms or using proprietary vendor software to determine the extent of damage and to devise response measures. Because emergency response missions may contain sensitive information, it is not common for data to be stored permanently. Quite often, the UAS team transfers the post-processed data and any supplemental files/animations to the requestor and does not retain a permanent database of the emergency mission.

3.2.2 Challenges and Recommendations

Emergency response missions using UAS involve coordinated action from multiple participating stakeholders to accomplish a common objective. Table 3-4 identifies the specific challenges for emergency response use cases during the three stages of UAS operations and groups them as technological, operational, or policy related. It also discusses applicable recommendations or mitigation strategies for agencies to overcome these challenges.

Table 3-4. Implementation challenges and potential recommendations for UAS adoption for emergency response.

Challenge Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
Technological/ System	Rapidly evolving technological landscape and advancements in capabilities (e.g., sensor payloads, support systems and software for mission control, data collection and processing)	Medium	Low	High	Emphasize performance specifications and require necessary equipment from consultants. Specific criteria to consider for UAS selection for emergency response is listed in the Task 2 report.
	Obscure images or videos reducing quality of data due to challenging field conditions (e.g., lighting, inclement weather, and other objects obscuring sensors)	Low	Medium	High	Invest in data processing software that uses AI and advanced image processing algorithms to address poor illumination or other occlusion in observed data. Refer to the Task 2 report for a comprehensive list of software for image processing.
	Limitations in flight planning software for inspections and environmental impacts (e.g., wind, climate) to safe, stable and consistent flights	High	Medium	Low	Increase capacity of UAS pilots to plan their flights with these factors in mind to help mitigate software challenges.
Procedural/ Operational	Procurement considerations and coordination challenges with multiple stakeholders for emergency response	High	Medium	Low	Develop interagency agreements with other participating governmental agencies including public safety, law enforcement, and first responders.

Challenge Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
					Establish C2 as process, function, and organization and communicate the structure to all stakeholders.
					Leverage novel procurement approaches to obtain necessary equipment and approvals for the mission (e.g. purchasing UAS under System Assessment and Validation for Emergency Responders Program by U.S. DHS; more details can be found here).
	Lack of UAS standards/policies or inadequate definition of specifications	High	Medium	Medium	Ensure incorporation of performance specifications related to UAS deployment for emergency response. Specific considerations include platform type, flexibility in accommodating different payloads, potentially longer flight durations, and obstacle avoidance sensors.
					Develop ICS hierarchy considering the UAS program under the Operations unit.
Regulatory/ Policy	Time constraints to obtaining required waivers for emergency response	High	Low	Low	Consider LAANC for obtaining waiver to access-controlled airspace near airports.
					Leverage UAS C2 organization through TICC for

Challenge Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
					expedited mission request and approval.

3.3 Public Outreach and Engagement (Rhode Island DOT)

State agencies employ a variety of approaches for public outreach and engagement efforts to ensure that the community and other interested stakeholders are informed about project development and delivery efforts. Quite often, engagement techniques to communicate project development include visual aids such as photorealistic images, videos, 3D models, and other aids. Using UAS for public outreach and demonstration has been an increasing trend. Agencies can deploy UAS to capture the current progress on construction jobsites and use the data to generate informative images (RGB) and videos to let the public know about anticipated lane closures, route detours, and traffic control measures in place. UAS can also provide timely aerial imagery and video at a high resolution for a more immersive perspective of undeveloped land for upcoming projects, which can play a crucial role in harnessing buy-in of public stakeholders for successful project delivery. Such immersive perspective is often hard to achieve using other alternatives.

Task 1 explored the operational profile of Rhode Island DOT in terms of its current UAS capabilities and identified deploying UAS for public outreach and engagement as a key area of interest for the agency. Task 2 documented the criteria for key technologies and systems requirements to consider for using UAS for public outreach and enlisted market-ready products available for immediate usage. Based on the findings from Tasks 1 and 2 and the interview conducted with agency staff to understand their existing approach and usage of UAS for public engagement, this section enumerates the challenges involved in integrating UAS for public engagement and suggests potential mitigation strategies to address some of the challenges.

3.3.1 Stages of UAS Operations for Public Outreach

The process workflow for using UAS for public outreach is divided into three stages—pre-flight planning, flight operation and data collection, and pre-processing of results. Appendix A-3 includes a graphical depiction of the process of public outreach and engagement.

3.3.1.1 Pre-flight Planning

This stage comprises planning activities required for evaluating office and field environments to ensure safe operations of the flight when deployed for public outreach and engagement. The process involves a clear understanding of the scope of the mission and the data requirements that inform the selection of appropriate systems and staffing needs. Existing guidelines from Rhode Island DOT on UAS operations need to be strictly followed regarding flight planning, operational risk assessment, training requirements, system selection, flight operations, data collection, and post-processing. System selection involves choosing efficient aircraft platforms (multi-copter type) and identifying sensor payloads (RGB cameras). Public outreach missions do not generally require sophisticated aircraft systems like other engineering-related applications. Instead, simple and easy operation can be the most important factor when choosing the right UAS system for public engagement and outreach efforts.

Any additional waivers required for FAA’s Part 107 regulations must be obtained. Public engagement operations usually require flights of shorter duration (20–45 minutes) and normally involve collecting RGB images and videos. A security plan is desirable to survey the site and ensure the safety of on-site personnel, public stakeholders, and others. The agency’s UAS Program Coordinator should use the results from the overall evaluation to make a go/no-go decision for the process to move to flight operations.

3.3.1.2 Flight Operations and Data Collection

This stage involves the mostly on-site processes to collect required data for public engagement, including progress on construction jobsites, road closures, and traffic operations. The crew includes in-house personnel or the consultant responsible for UAS operations and, at a minimum, should include an RPIC and a VO who meet the FAA training requirements and are familiar with UAS operations and Rhode Island DOT's policies. If required, an additional agency representative should be available on-site to supervise UAS operations. With the crew deployment complete, various preparatory activities for system set-up can be performed, including establishing GCPs (with or without RTK), assessing weather in the field, and ensuring necessary checks for communication using remote control. The RPIC would then perform a final authorization of the operation after completing all preparatory activities.

During operations, the key technical parameters of the mission, including altitude, speed, communication checks, battery performance (or power), must be monitored continuously and comply with data requirements. Data collection efforts for public engagement may need multiple flights depending on the extent of the area being covered and the level of detail required. Once the required data are collected, pre-landing checks must be carried out with clearance from VOs to ensure safe landing. Subsequently, post-flight checks are conducted, and the flight operation is logged with any notable incidents that occurred during the flight. The collected data are then downloaded (using a flash drive or transferred to the office using VPN) and calibrated with required corrections to determine accurate sensor location using GCP/PPK techniques.

If live transmission of data from the data collection phase is required, it is important to have appropriate communication protocols to engage with the public. Additional technological capabilities to consider include a wireless network for live transmission and real-time processing software solutions for analysis and relay of required imageries/videos. Qualified personnel can also be engaged as "public liaisons" to ensure that UAS-related technical details are translated into common language that can be easily consumed by the public and other stakeholders.

3.3.1.3 Post-data Processing

This stage involves processing the collected data to create photos, videos, and 3D models of the project conditions and translate them to graphical renderings and animations for public outreach efforts. Several desktop and cloud-based image processing and photogrammetric solutions are available to create high quality images and videos from the collected raw data. If the collected data are transmitted live, processing software should have capabilities of online/real-time processing of information. Once processing is complete, the post-processed data can be archived depending on the agency's digital data archival and retention guidelines.

3.3.2 Challenges and Recommendations

Table 3-5 identifies the specific challenges for the public engagement use case during the three stages of UAS operations and groups them as technological, operational, or policy related. It also discusses applicable recommendations or mitigation strategies for agencies to overcome these challenges.

Table 3-5. Implementation challenges and potential recommendations for UAS adoption for public engagement.

Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
Technological/ System	Rapidly evolving technological landscape and advancements in capabilities (e.g., sensor payloads, support systems and software for mission control, data collection and processing)	Medium	Low	High	Emphasize performance specifications and require necessary equipment from consultants. Specific criteria to consider for UAS selection for public engagement may include resolution requirements for images and videos collected and platform type.
	Limitations in flight planning software for inspections and environmental impacts (e.g., wind, climate) to safe, stable, and consistent flights	High	Medium	Low	Increase capacity of UAS pilots to plan their flights with these factors in mind to help mitigate software challenges.
Procedural/ Operational	Lack of standard operating procedures and safety policies	High	Medium	Low	Invest in preparing necessary guidelines (Virginia, Alabama, and Montana DOT guidelines) and adapt guidelines from specific use case examples (MnDOT, Louisiana DOTD).
	Communications challenges for public outreach and stakeholder engagement	Low	Medium	High	Consider engaging a liaison (public liaison officer) to translate inferences from UAS to terms that resonant with public stakeholders.
					Consider developing a UAS awareness campaign with a presentation to cover the following: - Agency goals and mission types/activities to support those goals. - Annual summary report on progress for the public. - Risk mitigation procedure for public safety.

Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
					· UAS program overview. · Aircraft and flight missions. · Flight crew credentials and experience. · Expected outcomes and community benefits. · All Federal, State, and local approvals.
					Invest in systems that produce simple graphical outputs from UAS (RGB images, videos).

3.4 Construction Inspection (Connecticut DOT)

Connecticut DOT's *Strategic Five Point Action Plan* prioritized the significance of the State of Good Repair and highlighted the need for enhanced safety and modernization of assets. Construction inspection often involves collecting various types of data to conduct QC checks and perform field sampling for verification testing and acceptance. UAS technology can play a pivotal role for volumetric assessment of earthwork and pavement layers to support quantity measurements and contract payments. UAS data may need to be enriched with surveying information from other digital inspection tools such as laser scanners, GNSS rovers, and total stations to ensure the completeness and accuracy required by inspection manuals.

Task 1 explored the operational profile of Connecticut DOT in terms of its current UAS capabilities and identified deploying UAS for construction inspection as a key area of interest for the agency. Task 2 documented the criteria for key technologies and systems requirements to consider for using UAS for construction inspection and enlisted market-ready products available for immediate usage. Based on the findings from Tasks 1 and 2 and the interview conducted with Connecticut DOT, this section enumerates the challenges involved in integrating UAS for construction inspection and suggests potential mitigation strategies to address some of these challenges.

3.4.1 Stages of UAS Operations for Construction Inspection

The process workflow for using UAS for construction inspection is divided into three stages—pre-flight planning, flight operation and data collection, and pre-processing of results. Appendix A-4 includes a graphical depiction of the process of construction inspection.

3.4.1.1 Pre-flight Planning

This stage comprises planning activities required for evaluation in office and field environments to ensure safe operations of the flight when deployed for construction inspection. The process involves a clear understanding of the scope and objectives of the task and the data requirements that inform the selection of appropriate systems and staffing needs. System selection involves choosing efficient aircraft platforms (fixed platforms for large construction jobsites) and identifying sensor payloads (RGB cameras/ infrared/LiDAR). Connecticut DOT's construction inspection manuals and its UAS policy for operations should be considered while preparing for the mission. The agency's inspection manual recommends detailed procedures for QC and quantity verification for various elements, including drilled shaft, drainage, excavations, work zones, concrete, cofferdam, pavement, and steel structures. Estimating quantities for earthwork and pavement are two of the key objectives for deploying UAS for highway construction inspection. Sensor payloads should be chosen to comply with the level of detail required to accomplish the objective. The level of vertical accuracy and adequate GSD (typically in the range of 2.5–5 centimeters [cm]) are important considerations in equipment selection for construction inspection. However, a lower range of GSD for construction inspection (~0.5cm) is recommended for accurate engineering analysis. While no standard exists (primarily because of a lack of data and because adoption is still in its infancy), it is often possible for UAS service providers to offer sub-centimeter accuracy in small, tightly controlled environment like construction sites.

If construction inspection requires traffic control, it may be beneficial to explore opportunities to coordinate with contractors to perform flight missions within the maintenance of traffic (MOT) schedule. An additional enhancement is available if the environment has reliable WIFI connectivity for caching base imagery maps for planning software in the field. WIFI or Bluetooth can also provide real-time data transfer from the field to the office for data processing.

Any additional waivers required for FAA's Part 107 regulations must be obtained. A robust flight plan should also be supplemented with a site survey to prepare for anticipated wind speed, precipitation, temperature, humidity, and altitude of operations. The field conditions can influence the selection of appropriate platform, payloads, and personnel. The agency's UAS Program Coordinator should use the results from the overall evaluation to make a go/no-go decision for the process to move to flight operations.

3.4.1.2 Flight Operations and Data Collection

This stage involves the on-site processes to collect required data for performing activities related to construction inspection. The crew to be deployed involves in-house personnel or a consultant responsible for UAS operations and, at a minimum, should include an RPIC and a VO who meet the FAA training requirements and are familiar with UAS operations and Connecticut DOT policies. If required, an additional agency representative should be available on-site to supervise UAS operations. With the crew deployment complete, various preparatory activities for system set-up can be performed. These activities include establishing GCPs (with or without RTK), assessing weather in the field, and ensuring necessary checks for communication using remote control under various scenarios for inspecting elements. The RPIC would then perform a final authorization of the operation after considering all the preparatory activities.

During operations, the key technical parameters of the mission, including altitude, speed, communication checks, battery performance (or power), must be monitored continuously and comply with data requirements. Element-level construction inspection may require multiple flights depending on battery life, weather conditions, and level of detail requirements for each element. Special attention should be given to:

- Adequate coverage and good working conditions of the GCPs on the field.
- Bluetooth or WIFI connectivity availability especially in areas where GNSS-signals could be lost on-site.
- Ensuring flight repeatability, especially on projects that require higher accuracy. The original flight patterns and method must be able to be repeated and reproduced.
- Stability and sturdiness of the platform to weather conditions adverse to small UAS aircraft missions.

A detailed list of UAS selection criteria is provided in the Task 2 report for construction inspection. Once the required data are collected, pre-landing checks must be carried out with clearance from VOs to ensure safe landing. Subsequently, post-flight checks are conducted, and the flight operation is logged with any notable incidents that occurred during the flight. The collected data are then downloaded (using a flash drive or transferred to the office using VPN) and calibrated with required corrections to determine accurate sensor location using GCP/PPK techniques.

3.4.1.3 Post-processing

This stage involves processing collected data (e.g., raw images and point clouds) and using them in terrain model volumetric calculations, measurements, and profiling. This information is uploaded in the agency's asset management system for future reference and planning for maintenance and rehabilitation. The collected data are verified for QC requirements as required for construction inspection. General thresholds for quality assurance (QA)/QC for this use case include achieving a GSD of 2.5–5 cm and a horizontal and vertical accuracy of 0.2–0.35 feet at a 95 percent confidence interval (Conver, 2019). Post-processing of GPS data should occur to ensure positional accuracy is improved.

Depending on the type of sensors used (RGB cameras/infrared /LiDAR), different types of post-processing techniques can be deployed to analyze the images. Images can be processed using several COTS platform or using proprietary vendor software to estimate quantities. These tools deploy photogrammetric techniques (triangulation) or appropriate methods for point cloud processing (including registration, feature detection/segmentation, filtering, and densification). Once processing is complete, the post-processed data can be archived depending on the agency's digital data archival and retention guidelines.

3.4.2 Challenges and Recommendations

Table 3-6 identifies the specific challenges for the construction inspection use case during the three stages of UAS operations and groups them as technological, operational, or policy related. It also discusses applicable recommendations or mitigation strategies for agencies to overcome these challenges.

Table 3-6. Implementation challenges and potential recommendations for UAS adoption for construction inspection.

Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
Technological/ System	Rapidly evolving technological landscape and advancements in capabilities (e.g., sensor payloads, support systems and software for mission control, data collection and processing)	Medium	Low	High	Emphasize technology specifications and require necessary equipment from consultants. Specific criteria to consider for UAS selection for construction inspection are listed in the Task 2 report.
	Lower positional accuracies of images collected from construction sites	Low	Medium	High	Set up frequent GCPs over construction sites or invest in a survey-grade GNSS platform onboard UAS and a base station to do RTK/PPK corrections on the image positions being recorded.
					Publish permanent GCP coordinates and implement QA/QC procedures to frequently compare image coordinates to published values.
	Limitations in flight planning software for different shapes and sizes of construction sites and purpose of inspections	High	Medium	Low	Increase capacity of UAS pilots to plan their flights with these factors in mind to help mitigate software challenges.
					Invest and select a flight planning software that can consistently produce repeatable and reproducible results.
Procedural/ Operational	Lack of standard operating procedures and safety policies or inadequate definitions of performance requirements for construction inspection	High	Medium	Low	Prepare and incorporate UAS criteria for construction inspection use case (example metrics include vertical accuracy of 0.2 feet and a GSD of 0.8 feet or better) (Conver, 2019).

Type	Description of the Challenge	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
	Challenges in navigating UAS through moving traffic on construction sites	Medium	High	Low	Collaborate with contractor to perform UAS flights in alignment with MOT schedules.
					Consider traffic control requirements for landing and take-off if fixed wing systems are used.
					Implement site safety guidelines to train all construction staff members on sUAS safety.
	Limitations in accuracy of data collection requirements for missions on larger construction sites	Low	High	Low	Conduct multiple flights with similar flight patterns and methods of data collection.
Regulatory/ Policy	Potential challenges in obtaining FAA approvals for construction inspection	High	Low	Low	Consider adopting VTOL or hybrid systems that comply with beyond visual line of sight (BVLOS) requirement for the flight.
					Consider LAANC for obtaining waiver to access-controlled airspace near airports.
					Collaborate with other interested state agencies for a joint UAS program (such as law enforcement, first responders, environment and natural resources agencies).

3.5 Traffic Monitoring (MassDOT)

Task 1 explored the operational profile of MassDOT in terms of is current UAS capabilities and identified deploying UAS for traffic monitoring as a key area of interest. Task 2 documented the data and systems requirements to consider for using UAS for traffic monitoring and enlisted market-ready products available for immediate usage. Based on the findings from Tasks 1 and 2 and the interview conducted with MassDOT, this section enumerates the challenges involved in integrating UAS for traffic monitoring and suggests potential mitigation strategies to address some of the challenges.

3.5.1 Stages of UAS operations for Traffic Monitoring

The process workflow for using UAS for traffic monitoring is divided into three stages—pre-flight planning, flight operation and data collection, and pre-processing of results. Appendix A-5 provides a graphical depiction of the process of traffic monitoring.

The first stage of UAS operation for traffic monitoring begins with process selection. Unlike other sUAS applications, traffic monitoring operations put more weight on the selection process than the subsequent steps that follow. When selecting a sensor for the application of traffic monitoring, it is important to maximize the field of view by selecting wide and larger camera sensors to capture as much data as possible in a single frame.

Another important aspect of the selection process is flight length of the aircraft because traffic engineers often request traffic data in hours, not minutes. Most sUAS currently available in the market can sustain flight for 30 minutes to a maximum of one hour. It is possible to swap multiple UAS aircrafts in the air to minimize loss of time, but this method produces two separate videos that need to be combined, and this process can be complex. The ideal method is to fly one platform for the entire length of time, and this can only be done using a tethered system with an on-ground power source. In the pre-flight planning stage, selecting a long duration aerial platform remains the biggest challenge; only a handful of tethered UAS are available. Because traffic monitoring sUAS applications require stationary, stand still, continuous flights, alternative types of sUAS platforms such as fixed wing and VTOL system are not applicable.

Any additional waivers required for FAA's Part 107 regulations must be obtained. In the case of traffic monitoring, flying above the 400-foot waiver can provide better data. Because most of the available platforms are equipped with a 20-megapixel resolution camera capable of capturing videos at 4K resolution (at a minimum), increasing flight altitude relates directly to increasing the amount of data. The resolution of the camera is generally sufficient to capture traffic data with flight altitude up to 800 to 1,000 feet.

Most flights for traffic monitoring purposes are stationary and continuous. During the pre-planning stage, pilots should prepare for anticipated wind speed, precipitation, temperature, humidity, and altitude of operations. The agency's UAS Program Coordinator should use the results from the overall evaluation to make a go/no-go decision for the process to move to flight operations.

3.5.1.1 Flight operations and data collection

This stage involves the processes conducted during flight operations to collect video data above the region of interest. The environments where traffic monitoring often occur involve heavy volumes of vehicular traffic during rush hours; therefore, a robust emergency response plan is required to avoid any incidents. The crew involves in-house personnel or a consultant responsible for UAS operations and, at a minimum, should include an RPIC for each UAS and a VO who meet the FAA training requirements and are familiar with UAS operations and MassDOT policies. During the winter, time of interest may overlap with sunset hours, and appropriate waivers should be acquired during the pre-flight stage.

In addition to capturing the video stream of live traffic flow, at least three GCPs in triangular formation should be captured in the interested frame. The GCPs must be visible at all time during the data capture. These data will serve as ground truth parameters to improve the accuracy of the traffic data processed by video analysis algorithm.

During operations, the key technical parameters of the mission, including altitude, speed, communication checks, battery performance (or power), must be monitored continuously and comply with data requirements. If a tethered system is used, it is essential to monitor brushless motor temperatures to prevent failure from overheating. Special attention should be given to:

- System component temperature because of long flight time (motors, transmitters, video feed unit).
- Safety and training, especially when deploying UAS in active traffic zones.
- Stability and sturdiness of the platform to adverse weather conditions.

A detailed list of UAS selection criteria is provided in the Task 2 report for traffic monitoring.

Once the required data are collected, pre-landing checks must be carried out with clearance from VOs to ensure safe landing. Subsequently, post-flight checks are conducted, and flight operations are logged with any notable incidents that occurred during the flight. The collected data are then downloaded and inspected.

3.5.1.2 Post-processing

This stage involves processing the collected data to extract traffic data from the video that are useful and meaningful to the traffic engineers. The post-processing stage of traffic monitoring data uses the most state-of-the-art software systems available in the field of computer vision. Because video analysis and vision segmentation and extraction algorithms are still in the early stages of commercialization, only a handful of traffic video analysis software is available for immediate application. Available software is explored in detail in the Task 2 report. One of the challenges in speed analysis of traffic monitoring is accuracy. To achieve the highest allowable precision with UAS traffic data, it is important to establish reliable ground truth points (control points and check points) and conduct flights during calm weather. The accuracy of the data largely depends on the flight operations because the post-processing parameters are hard fixed by camera parameters such as frames per second ratio and view angle of the camera. Nadir (strait down view angle) provides the most accurate result, but it also limits the amount of traffic data in a single frame.

3.5.2 Challenges and Recommendations

Compared to the existing method of traffic monitoring, sUAS does not offer a significant benefit under the current operational and regulatory framework. Therefore, regulatory operational restrictions remain the main challenge of sUAS traffic monitoring. If the UAS could fly at 1,200 feet and capture traffic flow during rush hour traffic until sunset, the amount of data captured may display flows and patterns of traffic in ways not previously captured. While technological challenges such as flying longer and capturing larger areas are present, these challenges can be resolved relatively easily compared to the regulatory restrictions. Therefore, it is highly recommended to expeditiously apply for regulatory approval processes in such circumstances with robust safety and operational plans in place to support higher and longer flights in busy urban roadway environments.

Table 3-7 identifies the specific challenges for the traffic monitoring use case during the three stages of UAS operations and groups them as technological, operational, or policy related. It also discusses applicable recommendations or mitigation strategies for agencies to overcome these challenges.

Table 3-7. Implementation challenges and potential recommendations for UAS adoption for traffic monitoring.

Type	Description of the Challenge	Level of Applicability or impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
Technological/ System	Rapidly evolving technological landscape and advancements in capabilities (e.g., sensor payloads, tethered systems)	Medium	High	Low	Emphasize performance specifications (flight time, positioning system) and ground control requirements. Specific criteria to consider for UAS selection for traffic monitoring are listed in the Task 2 report.
	Available video analysis tools to extract target data from the traffic data (e.g., pattern analysis, feature segmentation)	Low	Medium	High	Establish minimum standard accuracy and required type of data extracted from the traffic video data. Create a standard template for traffic data including vehicle count, velocity, and trajectory. Refer to the Task 2 report for a comprehensive list of software for video analysis.
	Limitations in flight monitoring software and environmental impacts (e.g., wind, climate) to safe, stable, and consistent flights	High	Medium	low	Make development of safety standards on long UAS flights that exceed one hour of continuous flight a common practice while flying near roadways involving high traffic volume.
Procedural/ Operational	Lack of standard operating procedures and safety policies or inadequate definitions of performance requirements for traffic monitoring	High	Medium	Low	Prepare minimum standard of procedures specific to the traffic monitoring sUAS flight. Emphasize detailed flight plan pre-submittal, including launch/landing point, crew locations, and emergency response.
	Operation in areas with high traffic volume during peak rush hours	Medium	High	Low	Train pilots to operate in high traffic zones (ensuring appropriate initial and recurring training requirements for the RPIC, VO, and other crew members).
		Low	High	Low	Use a tethered safety system or parachute system to prevent sudden crashes.

Type	Description of the Challenge	Level of Applicability or impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
	Operational hazard to avoid UAS system failure to the flow of traffic directly below				Avoid flying over the road or near the road at all costs.
					Place geo-fence requirement not to fly within a certain distance from the edge of the travel way.
Regulatory/ Policy	Height constraints to fly above the 400-foot ceiling	High	Low	Low	Consider prequalifying vendors based on experience obtaining waivers to fly above the 400-foot ceiling..
					Consider LAANC for obtaining waiver to access controlled airspace near airports.

3.6 Surveying and Mapping (New Hampshire DOT)

Among multiple applications of sUAS in various sectors, the surveying and mapping industry has been the leading proponent of adopting the technological leverage that sUAS provide. Since the inception of the technology, more and more surveying and mapping service providers have implemented sUAS as a supplementary or standalone service to the point where most of these firms now offer some sort of sUAS-related service. As the private sector rapidly adopts the technology in an increasingly competitive market, government entities and regulating body fall behind in developing necessary standards and methodologies to ensure data quality and public safety. Unlike sUAS applications such as marketing and public engagement, traffic monitoring, and as an inspection tool, oversight for surveying and mapping applications is crucial because of the liability associated with accuracy and data integrity. For this reason, integrating sUAS into surveying and mapping standards needs to be implemented by a regulatory body, with standard methodologies and recommendations necessary to protect the public and industry from potential lawsuits.

Task 1 explored the operational profile of New Hampshire DOT in terms of its current UAS capabilities and identified deploying UAS for surveying and mapping as a key area of interest. Task 2 documented the criteria for key technologies and systems requirements to consider for using UAS for surveying and mapping and enlisted market-ready products available for immediate usage. Based on the findings from Tasks 1 and 2 and the interview conducted with New Hampshire DOT, this section enumerates the challenges involved in integrating UAS for surveying and mapping and suggests potential mitigation strategies to address some of the challenges.

3.6.1 Stages of Operations for Surveying and Mapping

The process workflow for using UAS for surveying and mapping is divided into three stages—pre-flight planning, flight operation and data collection, and pre-processing of results. Appendix A-6 provides a graphical depiction of the process of surveying and mapping.

3.6.1.1 Pre-flight Planning

The pre-flight planning is the most important part of the process when conducting an sUAS flight for surveying and mapping. Like the conventional photogrammetry project, a certified photogrammetrist or sUAS mapping technician plans the flight pattern and placement of ground control targets based on the type, environment, and required accuracy of the project. In the case of an sUAS photogrammetry project, the person who prepares the pre-flight planning must understand the camera sensor, field of view, swath angle, and lens type to configure the flight path and altitude to meet the accuracy requirements. In the case of an sUAS LiDAR project, all parameters of the photogrammetry project and the characteristics of the Inertial Measurement Unit, GNSS receivers, and the trajectory planning are required by the operator.

Any additional waivers required for FAA's Part 107 regulations must be obtained. Additionally, the pilot and operator should be provided with a site survey to prepare for wind speed, precipitation, temperature, humidity, and altitude of operations. The field conditions can influence the camera parameters such as shutter speed, aperture, flight speed, and lens types, which can directly affect the quality of the data. Vibrations can cause significant blurring of the images depending on the aircraft type. The blurriness of the image can affect the accuracy of the result and must be mitigated prior to the flight. Homogenous cloud conditions help with data consistency by minimizing high reflectivity caused by the light; however, standard off-the-shelf sUAS cameras often react to lack of adequate lighting by reducing shutter speed and lowering aperture value setting which causes blurry images. Therefore, pilots and operators must be familiar with the camera and its behavior during various weather conditions to acquire the highest quality of data given the limitations of the equipment.

3.6.1.2 Flight Operations and Data Collection

The most challenging stage of sUAS surveying and mapping lies in the flight operations and data collection. Flights that occur near urban areas or that involve busy vehicular or pedestrian traffic place tremendous stress on the pilot and the operator. Although, safety planning and emergency mitigations are designed during the pre-flight planning stage to avoid potential risks, it is impossible to predict unexpected variables in the field. For example, continuous foot traffic under the pre-planned flight path can make the flight plan noncompliant to the FAA Part 107 rule because it violates flying directly over a person or people. Pedestrian traffic is one of the most frequent challenges when flying near an urban area. The RPIC should always be prepared to control foot traffic by placing signs, cones, and warning tape around the area directly under the flight path. The RPIC should also become familiar with the crew management by placing VOs at locations to intervene and execute emergency response should equipment failure occur. The RPIC is ultimately responsible for the safe operations of the aircraft, and the experience and knowledge of the RPIC is crucial for the successful completion of the flight mission.

Another important task during this stage is the collection of GCPs. Because most sUAS cameras are uncalibrated and non-metric, GCPs ultimately control the accuracy of the result. GCP data should be collected prior to the flight operations to familiarize the crew with the site. When mapping a small area that requires engineering grade accuracy, RTK GPS quality GCPs may not provide sufficient accuracy; therefore, a conventional total station survey is recommended. Mapping more than a 2-mile-long roadway corridor or 3D modeling of an apartment complex should be designed differently with different types of measurement equipment.

During the flight operations, the key technical parameters of the mission, including altitude, speed, communication checks, battery performance (or power), must be monitored continuously and comply with data requirements. The flight data (e.g., electronic speed controller output values, GPS signal status, roll/pitch/yaw parameters, transmitter input values, and battery voltage output) must be logged in the digital format to analyze in case critical equipment failure occurs. .

During a sUAS mapping flight, it is often necessary to pause the mission and replace the battery. Sometimes the time it takes to replace the batteries is longer than the actual flight time itself. During each battery swap, special attention should be given to:

- Potential change or damage of UAS components, especially with adverse weather conditions.
- Propeller conditions and motor temperature.
- Safety review when deploying UAS urban areas.
- Battery charge level or voltage balance of all batteries.
- Signal strength and responsiveness of the aircraft to the transmitter input.

Once the required data are collected, post-flight checks are conducted, and the flight operation is logged with any notable incidents that occurred during the flight. The collected data are then downloaded and inspected on-site for any discrepancy.

3.6.1.3 Post-processing

This stage involves three stages of processing to produce mapping deliverable. The first step includes inspecting the image data and post-processing the GCPs. The mapping technician inspects the images for overexposure and excessive blurriness and adjusts contract/brightness and color balance uniformly to the entire dataset. Then the technician post processes the GPS data to the correct coordinate system to match the image coordinate system. Raw GPS data could cause significant errors between the ground and grid coordinate system if not adjusted correctly on a long linear project. The photogrammetric processing software will spread this grid to ground error, and it may appear normal in the quality report. Because sUAS photogrammetry uses high overlap and many images, this error can remain unseen and unreported and displayed as an accurate result. This has become one of the most frequent challenges of sUAS surveying and mapping and is often caused by an inexperienced mapping technician or a surveyor.

Once the data are prepared, the second stage of the post-processing is to run aero-triangulation and reconstruction. Currently, all photogrammetric software requires a mapping technician to visually inspect the images and tag a corresponding GCP in each image. At this stage of the process, aero-triangulation often fails in multiple scenarios. For example, currently available photogrammetric software algorithms fail to aero-triangulate similar repeating patterns of texture such as leaves, water, faces of highly reflective buildings, or the tops of landfills. If sufficient common high contrast objects are not available to produce enough tie points, the aero-triangulation will fail or produce severely distorted results. To overcome this challenge, mapping technicians should go back to the flight planning stage and increase the flight altitude or increase the number of GCPs. Because of this limitation, heavily vegetated areas or areas with large bodies of water should be avoided from mapping by sUAS photogrammetry. The alternative option is to use LiDAR sensors on the sUAS platform to compensate for the limitations of photogrammetry. However, this approach is often expensive and not widely adopted throughout the industry.

The last stage of post-processing involves extraction and mapping. This stage is the most laborious and time consuming. Given that the aero-triangulation and reconstruction process have been completed successfully, the mapping technician can use the reconstructed model to extract desirable features. The data format at this stage can be either point cloud or 3D mesh model. One of the advantages of this method is that the mapping technician does not need to be trained like a conventional photogrammetric mapping technician. Numerous feature extraction software is available for different types of environments that provide simple methods of extraction.

3.6.2 Challenges and Recommendations

The consensus in the industry around using sUAS for surveying and mapping is that it provides a cost-effective auxiliary method of mapping that complements conventional surveying methods. It is not a replacement for large-scale conventional photogrammetry mapping, but it is a great tool to supplement the conventional land surveying project. It adds supplementary products such as orthometric images and 3D models, and it can be used to minimize field surveying time by extracting features to a certain extent. However, it is often reported that the photogrammetric process used by software algorithms does not produce repeatable data and is not reproducible. While technological challenge should not be underestimated, it is important to note that these types of errors can be minimized by careful planning and proper methodology. Additionally, photogrammetric limitations can be overcome by using LiDAR sensors on sUAS, but this method is not as accessible as the photogrammetric method and is often cost prohibitive.

Table 3-8 identifies the specific challenges for the surveying and mapping use case during the three stages of UAS operations and groups them as technological, operational, or policy related. It also discusses applicable recommendations or mitigation strategies for agencies to overcome these challenges.

Table 3-8. Implementation challenges and potential recommendations for UAS adoption for surveying and mapping.

Type	Description of the Challenges	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
Technological/ System	Rapidly evolving technological landscape and advancements in capabilities (e.g., sensor payloads, support systems and software for mission control, data collection and processing)	Medium	Low	High	Focus on the cost effectiveness of the system at the current time and build scalable and upgradable procedures and methods to easily incorporate evolving technology. Develop a technological landscape catalog to collect industry standard systems, including camera sensors, LiDAR sensors, and processing software used in surveying and mapping industry.
	Limitations on environment by photogrammetric mapping (e.g., trees, water bodies, highly reflective objects like glass, metal)	Low	Medium	High	Invest in sUAS LiDAR system or research sUAS LiDAR vendors.
	Limitations in flight planning software for mapping complex terrain and environment (e.g., buildings, towers, curvy roads)	High	Medium	Low	Research and select a flight planning software and develop. Train in-house pilots to compile a list of improvements and recommendations.
Procedural/ Operational	Lack of standard operating procedures and safety policies or inadequate definitions of performance requirements for surveying and mapping	High	Medium	Low	Prepare and incorporate UAS criteria for the surveying and mapping use case as well as accuracy and QC requirements for surveying and mapping.

Type	Description of the Challenges	Level of Applicability or Impact			Recommendations
		Pre-flight Planning	Flight Operations	Post-processing	
					Produce standard operating procedure guidelines for sUAS surveying and mapping applications. The guideline should include GCP placement requirements, post-processing report guidelines, and final accuracy QA/QC guidelines.
	Operation in urban areas or public areas with high traffic volume, pedestrian traffic, buildings, towers, and other aerial traffic such as helicopters and low flying aircrafts	Medium	High	Low	Train pilots to control traffic, operate in busy areas, build flight hours with the same aircraft. Equip pilot in command with avionic radios, install sUAS beacon lights. Set requirements for the RPIC, VO, and other crew members. Consider operating the sUAS in manual flight mode.
					Create standard safety guidelines for flying in urban areas under FAA Part 107 rule.
	Operating cameras and sUAS in various weather conditions for different types of projects	Low	High	Low	Train pilots and camera operators to become familiar with camera parameters.
					Build flight hours on the sUAS for the pilot.
					Invest in a weather-resistant sUAS platform.
Regulatory/ Policy	Obtaining required waivers for surveying and mapping	High	Low	Low	Develop relationship with FAA to expedite the waiver ticket when needed.
					Consider LAANC for obtaining waivers to access controlled airspace near airports.
					Create guidelines for documenting flight log, project details, and pilot and sUAS system maintenance.

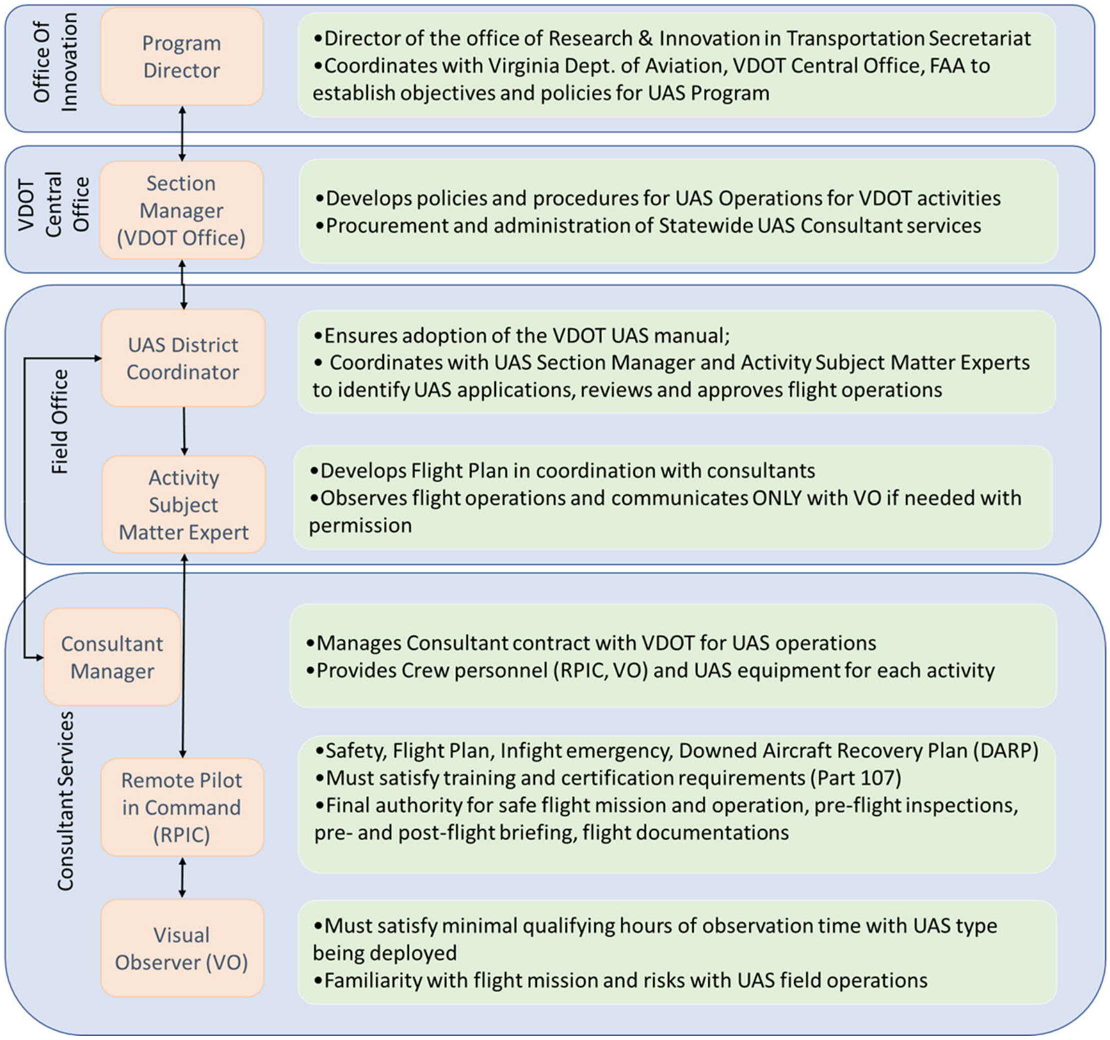
4.0 REVIEW OF BEST PRACTICES FOR UAS PROGRAM AND OPERATIONS

This chapter reviews the best practices that play a vital role in establishing and sustaining a UAS program. The foundational pillars of a successful UAS program include investing in organizational structure, developing key planning and operational guidelines (including safety and crew requirements), and exploring the options available for funding and operating the UAS program. These guidelines often assist in overcoming some of the initial institutional and procedural challenges faced by State DOTs whose UAS programs are nascent. DOTs with an existing UAS program can also benefit by orienting themselves to the best practices and insights offered in this section.

4.1 Organizational Structure

The organizational structure of a UAS program is an important consideration to ensure the technology can be promulgated across perceived or actual organizational boundaries. A recent American Association of State and Highway Transportation Officials (AASHTO) survey that scanned the state of practice of UAS programs at 50 State DOTs revealed that 36 of 50 State DOTs are using UAS for data collection to support various transportation use cases (AASHTO, 2019). State DOTs have taken different approaches to organizing their UAS activities; however, because UAS operations are atypical of traditional DOT functions, staffing a UAS program has been challenging (Federal Highway Administration, 2018). Some State DOTs have chosen to assign authority for UAS programmatic functions under their aviation or aeronautics division. Examples include Alabama DOT, Caltrans, MassDOT, and Washington State DOT. A few State DOTs have housed their UAS programs under one of the existing departments for project delivery. Examples include Maine DOT, where the UAS program is housed under the Chief Engineer. Connecticut DOT also hosts its UAS program under Bureau of Engineering and Construction. Some DOTs have also created a separate entity/center to coordinate agency-wide UAS operations across divisions. As an example, Ohio DOT's UAS program is housed under the Ohio UAS Center—a special unit under the Smart Mobility program. Utah DOT's UAS program is housed under Technology Advancement.

State DOTs with mature UAS operations have also detailed the organizational structure required to establish and monitor a UAS program. As an example, Virginia DOT's (VDOT) draft UAS operations manual includes a proposed organizational structure clearly delineating the authorities and chain of command for agency-wide deployment of its UAS program. It includes a UAS Program Director, a UAS Section Manager at VDOT Central Office who coordinates UAS activities of VDOT field staff, and consultants for various transportation applications. Figure 4-1 displays the organizational structure in VDOT's manual with primary responsibilities of the levels of authority (Virginia Department of Transportation, 2019).



Source: (Virginia Department of Transportation, 2019).

Figure 4-1. Illustration. VDOT's UAS program - organizational chain of command and responsibilities.

UAS programs for other DOTs such as Alabama, Utah, Pennsylvania, California (Caltrans), Iowa, Kansas, Minnesota, New Jersey, North Carolina, Kentucky (KYTC), and Colorado also offer detailed insights into the personnel requirements for staffing a UAS program. National Cooperative Highway Research Program (NCHRP) Project 20-68 A, Scan 17-01, notes that the key strategies of a successful UAS program include having a centralized authority and complete top-down support for the UAS program (Banks et al., 2018). The report reiterates that a strong relationship with the FAA is vital and that having dedicated staff assigned to the UAS program is often required to interpret and keep up with Federal, State, and local regulations. The range of mission profiles (use cases) to be supported through the UAS program also strongly informs selection of qualified individuals to support the UAS program and the procurement of relevant assets. A UAS policy that addresses the strategic questions concerning UAS usage for the purpose of conducting DOT-related business and procurement options available for UAS services is also beneficial. Creation of a UAS operations manual that details the planning and procedural requirements for UAS operations is another major milestone in setting up a functional and effective UAS program.

4.2 Mission Planning and Documentation

Transportation agencies need to prepare planning guidelines to leverage the full potential of solutions offered by UAS and to ensure safe operations of the UAS for transportation use cases. Several planning documents should be prepared and validated before deploying UAS operations to cater to specific use cases (Snyder et al., 2016).

For each individual mission, it is important to identify the purpose and desired deliverables (e.g., images, video) to determine if supplementary equipment or specifications are required. The next step is to study the operational environment; establish the perimeter; and understand key locations (e.g., take-off and landing zones, emergency landing areas, command center location), potential obstacles, and the potential to engage with commercial aircraft (if within 5 miles of an airport). All credentials, software, approvals, and permissions should be verified before flight operations.

The final preparation step is to develop a Mission Plan to capture all key information, steps, and plans for the mission. The Mission Plan is a concise document that includes four elements: the flight plan, the security plan, the data management plan, and the flight schedule. The Mission Plan should include sufficient detail such that there is no confusion during any step of the mission but should be brief enough to be quickly understood by all crew members in advance of the mission. Roughly three to five instructional bullets should provide enough detail for each element of the Mission Plan. Figure 4-2 provides a summary of the key information captured in each element of the Mission Plan.

Flight Plan	Security Plan	Data Management Plan	Flight Schedule
Outlines all key steps of the mission in chronological order.	Identifies key safety and security considerations (e.g., who should be expected at which location within the flying area).	Outlines data transfer/processing activities, storage requirements, and equipment specifications to fulfill the data collection objectives of the mission.	Outlines the timing for each stage of the flight plan, including start time and durations as necessary.

Source: (Snyder et al., 2016).

Figure 4-2. Illustration. Description of each element of the Mission Plan.

4.3 Safety Management Systems and Operational Risk Assessment

Identifying and managing the safety risks inherent in UAS operations is an important prerequisite to the integration of UAS with work processes of various State DOTs. FAA's revision to the Safety Management System Voluntary Program outlined four general components of a federally compliant and successfully managed Safety Management System, including safety policy, safety risk management, safety assurance, and safety promotion (Federal Aviation Administration, 2017).

- **Safety Policy** defines the organization's commitment to safety and identifies the accountable personnel for accepting safety risks for UAS operations at the office and field levels. For example, Texas DOT and VDOT use a project risk assessment process that captures the essential project information that are relevant for UAS operations and determines whether a pre-approval is required from the UAS District Coordinator for flight operations. Several DOTs have opted to have insurance as a key policy measure for managing operational and safety risks associated with

UAS. The insurance provides liability coverage for mishaps and incidents while operating UAS for projects and helps cover costs in the event of a lost UAS, an accident, or other damage to a certain extent. In general, the insurance companies require the following information (Snyder et al., 2016).

  - RPIC qualifications.
  - Operating manuals.
  - Maintenance logs.
  - Record of parts and add-ons purchased.

- **Safety Risk Management** procedures consist of tools and components to identify, evaluate, and control the safety risks from a UAS. Typically, the procedures involve a system analysis to identify hazards, methods to assess/quantify risks, and strategies to mitigate/manage risks. FAA developed a hazard identification and risk assessment process chart to help UAS remote RPICs analyze hazards related to the equipment being used and the environment in which the UAS is being operated. There are many methods and approaches to identifying hazards directly for RPICs when flying UAS, but one effective method is to use a “personal minimums” checklist as recommended by FAA (FAA, 2016) that covers:
  - Personal hazards (e.g., illness, medication, stress, alcohol consumption, fatigue, and lack of nourishment).
  - Aircraft hazards (e.g., preflight check, UAS operational condition).
  - Environment hazards (e.g., weather, emergency mitigations).
  - External pressures (e.g., timing, unhealthy safety culture, awareness of true abilities).
- **Safety Assurance** includes the processes that ensure that safety risks are controlled, and management measures are effective and exceed the organization’s objectives to identify and eliminate new hazards.
- **Safety Promotion** requires agencies to invest in training and communication of current UAS policies and any revisions to existing UAS policies to its employees and ensuring employee preparedness to manage mistakes in the field.

A few specific protocols are also identified based on experiences and lessons learned from other State DOTs across the county in developing UAS for various purposes. These topics are discussed below.

4.3.1 Emergency Procedures

This section summarizes best practices for emergency procedures as proposed in the report that Snyder et al. prepared for North Carolina DOT (NCDOT) (Snyder et al., 2016). Before flight operations are conducted, the flight crew is responsible for learning all important protocols as defined in the vendor operations manual. In case of an emergency during a mission, such as a UAS failure or an obstruction in the flight path, it is important for the RPIC to develop an emergency plan that can be deployed at any point in the mission and to brief the flight crew prior to flight operations. State DOT should develop an emergency checklist that outlines a response plan for any potential failure or emergency that could occur during a mission. Types of emergencies to consider and plan for in the checklist include (but are not limited to):

- Loss of Datalink communications.
- Loss of global positioning system (GPS).

- Autopilot software error/failure.
- Loss of engine power.
- Ground control system failure.
- Intruding aircraft in the UAS mission airspace.
- Battery warnings.

Most manufacturers build in failsafe features such as methods of stabilization with an automated return to land or loiter mode or fail-recovery software. It is important to test failsafe options before flight operations, and it is good practice to coordinate with vendors to ensure the safety check list is comprehensive and realistic given the capabilities and features of the UAS.

4.3.2 Flight Area and Airspace Management

This section summarizes best practices for flight area perimeter management as proposed in the report (Snyder et al., 2016).

Safety is the most important consideration in selecting take-off and landing sites. The RPIC is responsible for ensuring that the take-off and landing sites comply with FAA-issued authorizations and UAS flight limitations. The flight crew must be knowledgeable of all FAA flight boundaries and limitations. Additionally, the RPIC should identify primary launch and landing sites, alternate landing sites, and mission abort sites that minimize flying over populated areas and maintain a buffer of at least 50 feet between the UAS and non-essential personnel.

In deploying UAS for transportation use cases, it is also vital to safely integrate the UAS into the airspace environment from the approved flight area without posing any risks to other airspace users, the general public, or other properties. Some of the common approaches to ensure safe operations in airspace include:

- Ensuring compliance with the FAA mandate; equipping UAS with automatic dependent surveillance-broadcast and other traffic surveillance technology to broadcast real-time GPS location.
- Coordinating with the local airport in advance for missions that will be conducted near an airport; requiring written permission from the airport authority for operations within 5 miles of the airport.
- Requiring new UAS users consult the Association for Unmanned Vehicle Systems International's website http://knowbeforeyoufly.org/ or use the FAA's B4UFly application before embarking on flight operations.

4.3.3 Accident and Incident Reporting

National Transportation Safety Bureau's (NTSB) accident and incident reporting guidelines are documented in 49 CFR Part 830 (National Transportation Safety Bureau, 2010). It is important for operators to be knowledgeable of NTSB's definition for an accident versus an incident (as defined in 49 CFR Part 830) because the safety notification and reporting protocols vary based on this classification.

4.3.4 Communication Requirements

This section summarizes best practices for communications requirements as proposed in the Snyder report (Snyder et al., 2016).

Internal communications best practices include:

- Developing a defined decision-making structure to determine internal communication protocols among the flight crew.
- Making an observer responsible for all external communications during flight.

The RPIC is required to maintain direct two-way radio communication with the airport manager and airport air traffic controller (Class A or D airspace, Class E and G airspace if required).

Best practices for external communication include:

- Filing a Notice to Airmen with the Automated Flight Service Station.
- Identifying the phone number for the local emergency responder in advance of flight operations.

4.3.5 Equipment Maintenance Requirements

Chapter 7 of the FAA’s Part 107 Circular provides guidance on sUAS maintenance but does not explicitly outline a universal maintenance program because scheduled maintenance requirements may vary by manufacturer (FAA, 2016). Scheduled and unscheduled overhaul, repair, inspection, modification, replacement, and system software upgrades of sUAS and their components necessary for flight must be maintained in accordance with the manufacturer’s instructions. Typically, the manufacturer’s instructions will specify scheduled maintenance and replacement cycles based on time-in-service limits. It is important to adhere to manufacturer’s scheduled maintenance and replacement requirements to optimize the lifetime and safety of the sUAS. If the manufacturer does not provide sufficient maintenance guidance, Part 107 Circular recommends that the operator establish scheduled maintenance protocols by documenting time-in-service between all repairs, modifications, overhauls, and component replacements resulting from normal flight operations. It is also important to understand the component replacement cycles and consider the following before purchasing a UAS (Snyder et al., 2016):

- Check the warranty and after-sale service agreements.
- Understand availability of replacement parts.
- Identify a strategy to ensure spare parts are readily available (e.g., keep an inventory of spare part or find a reliable nearby dealer).

4.4 Crew Selection Requirements

Operating a UAS for transportation applications requires skilled personnel who are trained to understand specific areas of minimum aviation competencies, including applicable regulations, airspace, weather information sources and related effects on UAS operations, UAS loading, emergency procedures, flight crew resource management, radio communications procedures, determining the performance of UAS, physiological/human factors, aeronautical decision-making and judgment, airport operations, and aircraft maintenance and inspections. Beyond these minimum competencies, subject matter expertise in relevant transportation operations is important so that the data being collected are contextually accurate for decision making. State DOTs should establish and maintain both an initial and continuing training program and maintain relevant documentation. Table 4-1 outlines the minimum qualifications for various personnel involved in UAS operations. Several agencies have requested that personnel have additional knowledge beyond the minimum requirements. As an example, Ohio DOT, requires knowledge in data aspects related to UAS operation such as knowledge of data processing software, video and two-dimensional software packages, and reading and interpreting thermal data (Banks et al., 2018).

Table 4-1. Minimum qualifications by role.

Role	Qualifications
RPIC	- FAA UAS certification - State certification and permits - Medical requirement (Class II Medical Certificate recommended)
UAS Operator	- FAA UAS certification - Original Equipment Manufacturer UAS qualification training - State certifications and permits - Medical requirement (Class II Medical Certificate recommended) - UAS type currency (via pilot logbook) and continuation training

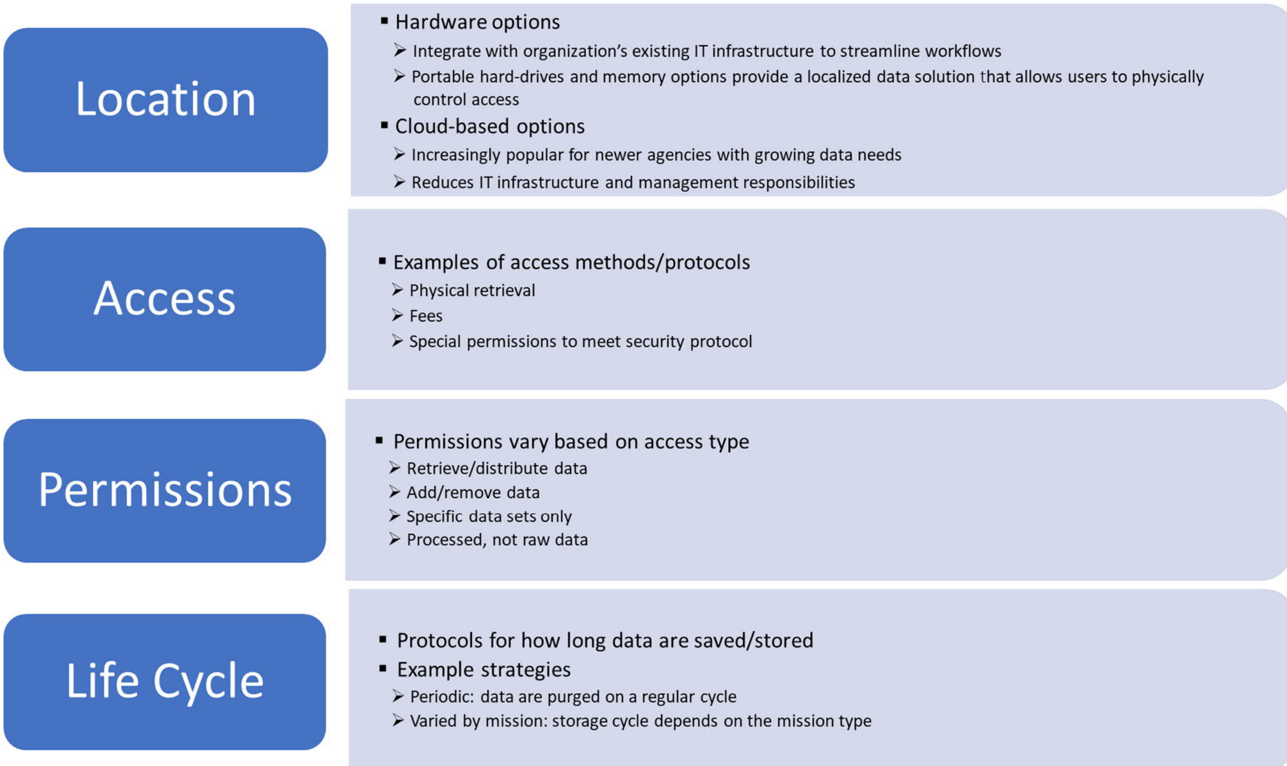
Visual Observer (VO)	- Ideally, similar qualifications to the RPIC for redundancy, but not required
	- Medical requirement (Class II Medical Certificate recommended)
	- UAS operational experience and specific platform certifications
	- Should be familiar with the following:
	  - 14 CFR 91.11, Operating Near Other Aircraft
	  - 14 CFR 91.113, Right-of-Way Rules
	  - 14 CFR 91.155, Basic Visual Flight Rules Weather Minimums
	  - Knowledge of air traffic and radio communications, including the use of approved air traffic control/pilot phraseology
	  - Knowledge of appropriate sections of the Aeronautical Information Manual

Data Analyst	- Subject matter expertise depending on the mission type, desired deliverables, and analysis to be performed - Familiarity with the software to be used for data processing - If in the field, medical requirement (Class II Medical Certificate recommended but optional)

Source: Adapted from (Snyder et al., 2016).

4.5 Data Storage and Security

The four main elements of data and storage security include establishing : location needs, access needs, permissions protocols, and life-cycle protocols based on the organization's data needs (Snyder et al., 2016). The key consideration for determining the location is deciding between a hardware or cloud-based storage option. Location selection depends on the current capabilities and future goals for the organization and the UAS program as described in Figure 4-3. Access methods/protocols will vary based on the location selection and security protocols. Well-defined permissions rules (e.g., who can access the data and what can they do with the data) based on roles and qualifications are important for audit and security purposes. As data needs grow within an organization, the organization should develop a well-defined life cycles for how long data should be saved once stored based on the purpose of the data to strike a balance between maintaining important data but ensuring obsolete data are not unnecessarily taking up storage space.



Source: (Snyder et al., 2016).

Figure 4-3. Illustration. Summary of key considerations for data management and security.

Because UAS have many complex capabilities and can quickly produce large quantities of data for processing and analysis, it is important to develop a comprehensive data management plan that considers various layers of data storage and security. If the data management protocols are not well established in advance of data collection, data quantities can quickly become overwhelming and disorganized. The DOT may already have a data management policy in place that can be adapted to suit UAS data integration.

4.6 Operations Models for UAS Program

The decision to fly using agency resources compared to consultant resources is a decision that should be made early in the mission planning stage. The decision support construct that facilitates this process is largely based on requirements including project characteristics, available resources, capabilities, and data governance. Relying solely on agency resources can limit scalability, affect workload balancing, and increase agency exposure to liability, but it can accelerate integration across service areas. On the other hand, relying solely on consultant resources may be a prudent first step to integrating UAS technology into workflows while limiting agency liability. In the latter case, agencies should use a qualified inspector to evaluate the work and assure the quality of services and deliverables in the spirit of fiduciary stewardship to the public. To retain proficiency and optimize flexibility in using UAS technology, a hybrid approach with agency and consultant resources can be an effective practice to consider. Table 4-2 summarizes the benefits and challenges of various UAS operations model alternatives.

Table 4-2. UAS operations model alternatives.

Model	Benefits	Challenges
Agency Purchase	• System operations under agency control • System always available to agency • Maintain law enforcement evidence chain of custody	• High acquisition cost and maintenance cost • Agency responsible for maintenance • Additional staff required for operations and maintenance • Operators unavailable for other agency tasking • Cost of operator certification
Agency Lease with No Maintenance Agreement	• Lower cost compared to purchase • Technology insertion and system upgrades could be part of the leasing agreement • Maintain law enforcement evidence chain of custody	• Additional staff required for operations and maintenance • Cost of operator certification
Agency Lease with Maintenance Agreement	• Contractor responsible for maintenance • Technology insertion and system upgrades could be part of the leasing agreement • Maintain law enforcement evidence chain of custody	• Additional staff required for operations • Cost of operator certification
Services Contract	• All costs rolled into cost per flight hour • Purchase flight hours needed • Purchase hours based on budget • Contractor responsible for maintenance • Contract for new capabilities as technology develops • Contractor provides Section 333 exemption	• Non-agency contractor operations • High cost per flight hour • Data collected by contractor • Need process for law enforcement to collect and maintain evidence chain of custody

Source: (Snyder et al., 2016).

4.7 Funding and Managerial Support

Identifying dedicated funding sources for initial implementation and continued sustenance of a UAS program is critical to enhance predictability and success in UAS operations. In the past, State DOTs have managed to obtain federal grants to support UAS implementation in their operations using the Federal Highway Administration's (FHWA) Technology and Innovation Deployment Program, State Transportation Innovation Councils Incentive Program, and

- State Planning and Research Program.

State DOTs that are concerned with ensuring public safety can use grants available under Homeland Security/Federal Emergency Management Agency (FEMA) to purchase UAS if its intended use is to support first responders, emergency medical service, and pre-disaster mitigation. A UAS program dedicated for disaster surveillance and rescue efforts could also be funded through the FEMA's Hazard Mitigation Grant Program. Instances also exist where State DOTs collaborate with other interested State agencies and academic institutions for a joint UAS program (such as law enforcement, first responders, and environment and natural resource agencies, among others).

Another common challenge often cited by State DOTs looking to start a UAS program is lack of leadership support at the executive level. This process requires systematic engagement of the decision makers on an ongoing basis to ensure that decision makers understand the incremental value and potential benefits offered by UAS technology for transportation use cases. Leadership buy-in and trust are critical to ensure the program is sustained on a long-term basis. To achieve this goal, State DOTs establishing a UAS program should consider engaging a "cultural champion" who is knowledgeable and has experience in both traditional work processes in transportation projects and the operational workflow of UAS technology. This champion needs to disseminate required information on UAS services across all departments in the agency that stands to benefit from its implementation. State DOTs can also consider organizing periodic information sessions and field workshops to demonstrate the safety and efficiency of UAS technology.

5.0 SUMMARY AND CONCLUSION

UAS technology provides unique opportunities to collect required digital data for several transportation applications in a cost-effective manner. This report builds on the previous work conducted for the project that included an extensive review of current profiles and maturity of the New England State DOTs' use of UAS and documentation of technologies and support systems. It included a detailed review of FAA regulations that govern UAS implementation for transportation use cases. Part 107 regulations that govern sUAS (weighing less than 55 pounds) are of particular interest for transportation applications because most of the requirements for data collection can be met using the aircrafts and systems that pertain to this category. Part 107 waivers offer reliable routes to obtain approvals for missions that require exceptions to the stated regulations. Key findings from the analysis are summarized below.

- On average, it required around 40 hours to prepare and submit a waiver application. The study also concluded that most of the waivers were approved within 60 days or less.
- Waivers for nighttime operations remain the largest category approved by FAA largely because of an optimized waiver approval process and better understanding of hazards and mitigation strategies by FAA (such as illumination, VO presence, anti-collision lighting).
- Technologies (sensor payloads) and tactical methods to ensure safe operations (such as C2 link, detect-and-avoid, see-and-avoid) increase chances of approvals for Part 107 waiver applications in general. Highlighting the strategies for minimizing risks and including records of flight hours and qualifications of the flight crew in handling similar aircraft to support similar operations are also effective approaches that are often included in successful waiver applications.
- A close coordination between the Operations team and the responsible division for UAS in the State DOTs is vital to ensure documenting all the required details for waiver application process. A good working relationship with FAA can also expedite requests for information and approval cycles.

The report also included detailed process maps for UAS planning and operations to support each of the six selected transportation use cases. The process maps rely on existing UAS manuals and individual use case guidelines/specifications at the DOTs. Specific implementation challenges focusing on technology, policies, operations, and organizational issues are identified, and recommendations are developed to address the challenges in practice. Table 5-1 provides a concise summary of the major procedural challenges for the use cases noted during the case studies and offers insights on potential ways to overcome them.

Table 5-1. Summary of procedural challenges of UAS operations for selected use cases.

Use Case	Procedural Challenges	Mitigation Strategies
Bridge Inspection	• Operational constraints in confined space environments • Potential loss of signal flying beneath the deck of the bridge • Delay in acquiring FAA waivers for individual inspection sites	• Invest in collision-tolerant drones. • Implement multi-pilot operational control for manual takeover of missions. • Bundle multiple sites into an airspace map and obtain COA for flights that establishes operational ceilings based on proximity to airports (e.g., MnDOT). If required, considering LAANC for obtaining a waiver to access-controlled airspace near airports.

Use Case	Procedural Challenges	Mitigation Strategies
Emergency Response	• Coordination challenges with multiple stakeholders for emergency response • Need for expedited approval and management of UAS missions for emergency response	• Develop interagency agreements with other participating governmental agencies. • Communicate the hierarchy of ICS and follow the UAS C2 for mission approvals.
Public Outreach and Engagement	• Communications challenges for public outreach and stakeholder engagement	• Consider engaging a team of public liaison officials to translate inferences from UAS mission to terms that resonant with public stakeholders.
Construction Inspection	• Challenges in navigating UAS through moving traffic on construction sites • Complying with high accuracy data requirements for quantities estimation (vertical accuracy and GSD)	• Collaborate with contractors to perform UAS flights that align with MOT schedules. • Invest in sensor payloads, GCP set-up, and RTK/PPK GNSS systems and ensure flight repeatability to meet high accuracy requirements.
Traffic Monitoring	• Potential long flight times for traffic monitoring • Potential risks for deploying UAS in active traffic zone	• Consider using tethered systems and continuous monitoring of system health (motors, transmitters, video feed unit). • Avoid the mission to fly over live traffic and examine complete closures (if possible); focus on safety and training.
Surveying and Mapping	• Ensuring compliance with high accuracy requirements for imageries and other deliverables (digital surface models, digital terrain models) • Launching survey operations in urban areas or public areas with high traffic and pedestrian volume, buildings, towers and other low-flying air traffic.	• Invest in sensor payloads and support software systems for processing GPS corrections, aero-triangulation and reconstruction, and feature extraction and mapping. • Train pilots to control traffic, operate in busy areas, develop urban area hazard assessment checklist, and build flight hours with the same aircraft.

While the challenges listed above are deduced based on case study interviews with New England State DOTs, the proposed mitigation strategies reflect a collective understanding of potential solutions to address the issues based on lessons learned by other agencies and the experience of the research team in deploying or supporting UAS missions. These mitigation strategies should be considered as potential pathways to address the problems and should not be construed as overriding any of guidelines that exist in New England State DOTs in this regard. The subsequent task of the project will develop detailed implementation plans for UAS missions for the transportation applications examined as part of the project.

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7.0 APPENDICES

Process Maps