New England Transportation Consortium (NETC)

NETC 18-3

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

Final Report

Develop Implementation Procedures for UAS Applications

March 22, 2021

This report, prepared in cooperation with the New England Transportation Consortium, does not constitute a standard, specification, or regulation. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views of the New England Transportation Consortium or the Federal Highway Administration.

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16. Abstract Unmanned aircraft systems (UAS) technology is proving to enhance State Department of Transportation (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. This final project report includes a topical review of existing New England DOT Operational Manuals and Policy directives to evaluate the adequacy of the guidelines against key requirements to support UAS missions. Implementation plans for six use cases based on information available from existing guidelines and case study interviews conducted with New England State DOTs are also included. These implementation procedures are derived based on a holistic understanding of mission objectives, existing capabilities, and developing appropriate planning and operations strategies. These procedures act as supplementary guidelines for the UAS use cases, along with the existing standard operating procedures and policy documents in place at the 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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ACRONYMS

3D	three dimensional
BVLOS	beyond visual line of sight
CCTV	closed-circuit television
CFR	Code of Federal Regulations
cm	centimeter
COA	Certificate of Waiver or Authorization
CORS	Continuously Operating Reference Station
DARP	Downed Aircraft Recovery Plan
DOT	Department of Transportation
DSM	Digital Surface Model
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Flight Risk Assessment
GCP	ground control point(s)
GNSS	Global Navigation Satellite System
GPS	global positioning system
JARUS	Joint Association for Rulemaking of Unmanned Systems
LAANC	Low Altitude Authorization and Notification Capability
lbs	pounds
lidar	Light Detection and Range
MassDOT	Massachusetts Department of Transportation
ORA	Operational Risk Assessment
PPK	Post Processing Kinematics
REMOTE ID	Remote Identification (to help identify drone in flight)
RPIC	Remote Pilot in Command
RTK	Real Time Kinematics
SOP	standard operating procedure
SORA	Specific Operational Risk Assessment
sUAS	small unmanned aerial system
UAS	unmanned aerial systems
UAV	unmanned aerial vehicle

USC	United States Code
VO	Visual Observer
VTrans	Vermont Agency of Transportation

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1.0 INTRODUCTION

Unmanned aerial systems (UAS)[1] have seen increased use in the transportation sector because they offer the ability to collect high-quality information for site mapping, monitoring, and inspection in a safe and reliable way, including, and especially, in environments that possess significant constraints for human-based data collection. Several public agencies have been increasing their investment in UAS capabilities to support a myriad of missions. Enhancements on the technological front, including increasing cost-effectiveness, the broader availability of the services, and changes to the regulatory ecosystem for commercial applications, call for a more strategic approach to investments to fully leverage opportunities for the scalable, sustainable, and widespread integration of UAS to support various missions.

Prior tasks of this research project focused on reviewing the primary components for establishing and sustaining a UAS program and evaluated existing New England State Departments of Transportation (DOT) UAS programs. Technological systems and specifications to deploy UAS for various use cases were also documented with their potential implementation challenges. The objective of Task 4 is to develop procedures to support the planning and deployment of UAS for transportation applications for New England State DOTs. The report reviews existing guidelines, standard operating procedures (SOPs), and UAS policies at the DOTs to document current requirements associated with responsible authorities, operational requirements, procurement approaches, and other policy restrictions. The topics of a typical SOP for a UAS program are presented along with a discussion of the New England State DOT guidelines that align with the requirements for that topic. In addition to the standard requirements outlined in the SOPs, implementation procedures are described to offer insights for the agencies to consider when deploying UAS for specific transportation use cases. The following UAS use cases are evaluated in detail:

- Emergency response and recovery (Vermont Agency of Transportation or VTrans).
- Public outreach and engagement (Rhode Island DOT).
- Bridge inspection (Maine DOT).
- Surveying and mapping (New Hampshire DOT).
- Construction inspection (Connecticut DOT).
- Traffic monitoring (Massachusetts DOT or MassDOT).

The data collection for this effort included SOPs, policy manuals, and information gathered from case study interviews (Task 3). The implementation procedures are developed to assist in the administration of specific use cases. They are not intended to override any existing DOT or Federal, State, and local guidelines governing UAS implementation in the particular agency. The recommendations and methods presented herein would be of interest to the members of a UAS program of an agency and to other departments or divisions interested in using UAS to support their operational requirements.

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[1] For the purpose of the document, the term unmanned aerial systems (UAS) or unmanned aerial vehicles (UAV) refer to small unmanned aerial systems (sUAS) as defined under the Federal Aviation Administration's 2016 circular "*AC 107-2: Small Unmanned Aircraft Systems (sUAS)*."

2.0 STANDARD OPERATIONAL REQUIREMENTS FOR USE CASES

The use of UAS for commercial operations has expanded significantly over the past decades. Advancements in sensing technologies and support systems and the emergence of a regulatory framework (e.g., 14 Code of Federal Regulations [CFR] Part 107) have created opportunities for transportation agencies to explore and deploy UAS for a variety of missions. Public agencies can operate UAS under two primary rule sets: 14 CFR Part 107 or Public Aircraft 49 United States Code [USC] §40102(a) (41) and 49 USC §40125, and it may be beneficial to have the capability to perform missions under both. Public Aircraft operations require a formal application process for government agencies, law enforcement, and public safety entities to use these rules. Having a Public Aircraft Certificate of Waiver or Authorization (COA) provides more flexibility than solely using Part 107 rules because it provides additional flexibility to operations using UAS. Table 2-1 summarizes the characteristics of Public Aircraft vs. Part 107 operations.

Table 2-1. Part 107 vs. public aircraft operations.

	Aircraft Requirements	Pilot Requirements	Airspace Requirements	Types of Operations
Part 107	UAS <55 pounds (lbs)	Part 107 remote pilot certificate with small UAS rating	Airspace waiver or authorization for Class B, C, D, E airspace.	• Visual line of sight • Daytime • Class G • 400 feet above ground level • Not over people* OR waiver provisions
Public Aircraft	Self-certification by the public agency	Self-certification by the public agency	Blanket COA or Standard COA for specific airspace	• Public Aircraft Operations (AC 00-1.1A) • UAS Test Site Operations

*Operation of Small Aircraft Systems over People Amendment to 14 CFR Part 107 allows flights over moving vehicles and people. Rule amendments become effective March 16, 2021.
Source: Data derived from (FAA, Gardner, Scott; Petronis, Karen, 2018)Gardner and Petronis, 2018

The Federal Airline Administration (FAA) Remote Identification or Remote ID (14 CFR Part 89) rule and Operation of Small Unmanned Aircraft Systems over People, Part 107 amendment, effective March 16, 2021, will enable additional operations to be performed safely. These are critical milestones for sUAS users.

Remote ID provides the ability for UAS to broadcast identification and location information that can be received by other parties. This will be critical for the integration of UAS into the National Airspace System and will be an effective tool to help law enforcement and other Federal agencies find and identify UAS that appear to be flying in an unsafe manner or where it is not permissible to fly. Remote ID will be required for most UAS operating in U.S. airspace. Figure 2-1 illustrates ways that UAS pilots can meet the requirements of the Remote ID rule.

Figure 2-1. Illustration. How drone pilots can meet the requirements of the Remote ID rule.

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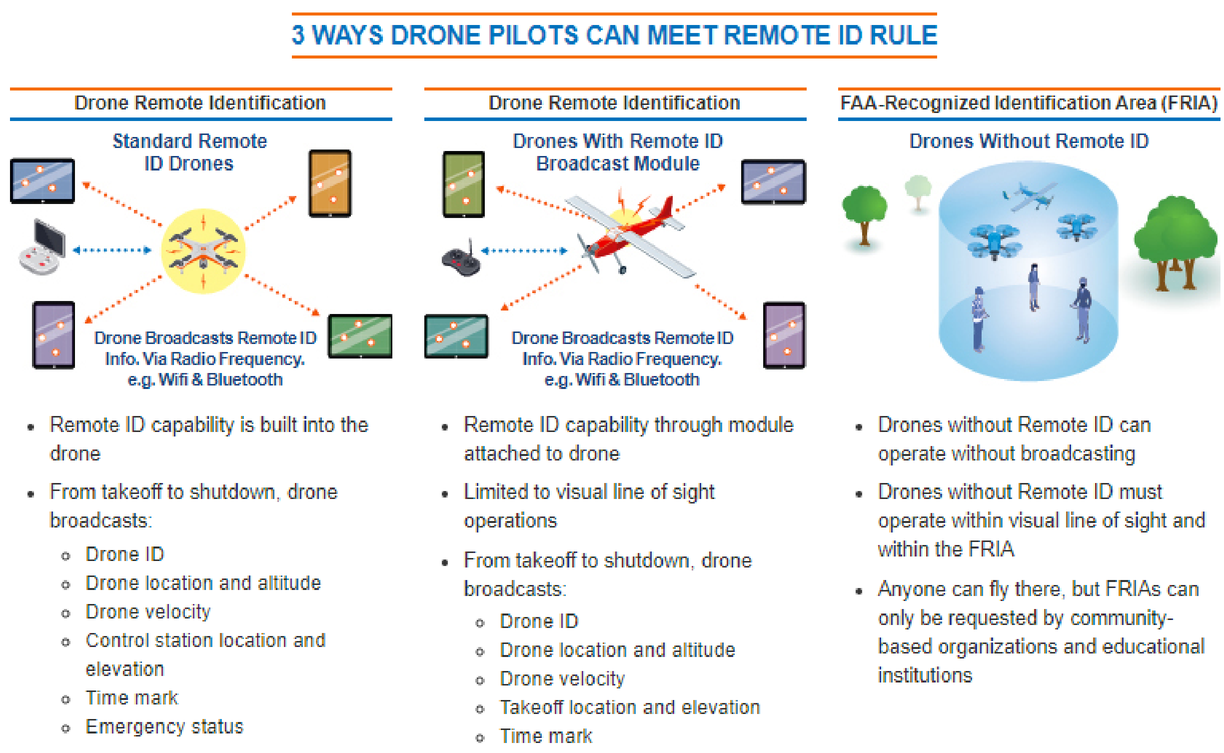


Source: (Federal Aviation Administration, 2021a)

The original release of 14 CFR Part 107 did not permit small unmanned aircraft operations at night or over people without a waiver. With the amendments to Part 107, flights over people, flights over moving vehicles, and operations at night will be allowed. UAS have been classified into categories that each have their individual requirements to enable flights over people and moving vehicles. Most operations conducted by a public agency will typically fall under Categories 2 and 3. For this document, only categories 2 and 3 are addressed. Table 2-2 summarizes the new guidelines for operations over people.

Table 2-2. FAA UAS operations over people requirements.

Category of UAS	Weight Eligibility	Requirements
Category 2	• Weigh more than 0.55 lbs but less than 55 lbs • Do not have an airworthiness certificate under part 21	No remote pilot in command may operate a small unmanned aircraft in sustained flight over open-air assemblies unless the operation is compliant with Remote ID.
Category 3	• Weigh more than 0.55 lbs but less than 55 lbs • Do not have an airworthiness certificate under part 21	A remote pilot in command may not operate a small unmanned aircraft over open-air assemblies of human beings. May only operate sUAS over people if: • The operation is within or over a closed- or restricted-access site and all people on site are on notice that a small UAS may fly over them; or • Does not maintain* sustained flight over any person unless that person is participating directly in the operation or located under a covered structure or inside a stationary vehicle that can provide reasonable protection from a falling small unmanned aircraft.

*Sustained flight over an open-air assembly includes hovering above the heads of persons gathered in an open-air assembly, flying back and forth over an open-air assembly, or circling above the assembly in such a way that the small unmanned aircraft remains above some part the assembly. Sustained flight over an open-air assembly of people in a category 2 operation does not include a brief, one-time transiting over a portion of the assembled gathering, where the transit is merely incidental to a point-to-point operation unrelated to the assembly.
Source: (Federal Aviation Administration, 2021b)

Operations over moving vehicles will also be allowed with the amendments to 14 CFR Part 107. The new regulations are similar to those covering the operations over people with the inclusion of the following:

- The small unmanned aircraft must remain within or over a closed- or restricted-access site, and all people inside a moving vehicle within the closed- or restricted-access site must be on notice that a small unmanned aircraft may fly over them; or
- The small unmanned aircraft does not maintain sustained flight over moving vehicles.

Night operations are included under the amendments of 14 CFR Part 107. To fly small unmanned aircraft at night requires adherence to the following two conditions:

- The remote pilot in command (RPIC) must complete an updated initial knowledge test or recurrent online training.
- The small unmanned aircraft must have lighted anti-collision lighting visible for at least 3 statute miles with a flash rate sufficient to avoid a collision.

Some of the common use cases explored as part of this project include the application of UAS for emergency response, public outreach and engagement, bridge inspection, surveying and mapping, construction inspection, and traffic analysis.

Agencies need to dedicate resources to develop fundamental guidelines at a programmatic level to manage the safe and efficient deployment of UAS across different missions. These guidelines ensure that UAS operations follow safe and established procedures for flight planning, mission deployment, data collection, and processing; they also ensure that the mission remains compliant with the governing Federal, State, and local regulations. SOPs are an essential framework document that entails these guidelines and generally applies to all UAS operations carried out by the agency through its in-house staff or any service providers/consultants working on its behalf. Adherence to the procedures outlined in the SOPs help office staff and field crew carry out complex operations predictably and consistently and achieve operational efficiency.

This chapter enumerates the key topics that constitute a holistic SOP for deploying UAS for transportation operations. Each topic described below is based on industry best practices and accompanied by a review of existing guidelines from New England DOTs for the particular area. Connecticut Department of Transportation (2019) and Vermont Agency of Transportation (2020) have developed detailed SOPs that govern their UAS programs and field operations. Massachusetts Department of Transportation, (2017) published a document that includes an interim drone policy and lays out legal and standardized methods to deploy UAS for various missions. New Hampshire Department of Transportation (2017) developed a policy directive that states the responsible authorities and approval requirements for UAS missions. Rhode Island DOT is in the initial stages of developing detailed guidelines to establish and sustain a UAS program.

The subsequent sections outline the key topics of an SOP for a UAS program, followed by an analysis of existing New England DOTs' guidelines to meet those requirements. While the identified topics are primarily focused on the transportation sector, relevant UAS programmatic guidelines are included from service providers and authorities from other industries, including energy, telecommunication, and buildings.

2.1. ORGANIZATIONAL STRUCTURE

Agencies need to establish a clear organizational structure for their UAS program to enable safe and efficient use of the technology to meet operational requirements across their various departments. Many State DOTs have chosen to house their UAS program under their Division of Aeronautics or Aviation to leverage the opportunity to share existing expertise in staffing and devising guidelines for UAS operations. Some agencies prefer to house the UAS program within other agency functional divisions (e.g., Surveying, Engineering, or Construction) if the aeronautics division is relatively new to UAS or if the expertise to launch a UAS program within one of the other divisions meets various missions' operational requirements. A sample of common UAS program structures is provided in Appendix 6.1. The main drivers that can justify an in-house (separate) UAS program include:

- Sufficient staff availability, RPICs and visual observers (VOs), and systems in-house to support the missions.

- Large number of missions with short turnaround time (from approval to flight operations and data processing).
- Ability to meet Part 107 or Public Aircraft Operation requirements.
- In-house knowledge and expertise of UAS and aeronautics.
- Centralized authority and top-down support.

Some DOTs (e.g., the Ohio UAS Center) manage and operate their UAS program while also using it as a shared resource to support the UAS requirements of other State and local agencies. This approach facilitates the exchange of knowledge and development of best practices and guidelines that are broadly applicable across many agencies that rely on UAS capabilities to meet their operational requirements. The key factors that favor a shared organizational structure include:

- Potential to offset operational costs and/or share mission benefits and lessons learned.
- Availability of more significant expertise in another peer agency in the State.
- Greater flexibility in the State regulations to set up a joint UAS program.
- Seamless data management workflow to support mission requirements of all participating agencies.
- Shared FAA COA.

The SOP manual should include an organizational hierarchy (in-house or shared) with clearly defined roles and responsibilities of all the key personnel involved in office and site planning, field operations, and post-processing UAS deployment phases. Most transportation agencies have a designated leader for the UAS program (such as Program Coordinator or Manager) who ensures the adoption of the SOPs and policy directives of the agency. Typically, they also coordinate and approve all missions conducted by DOT staff or their consultants. A UAS committee or working group comprising representatives from various divisions may also be necessary to prepare and validate the SOPs and oversee approval requests for use cases. An authority knowledgeable in aeronautics should be identified to liaise with the FAA and other participating authorities at the State and local levels. This person can validate the regulations influencing the UAS program and streamline the waiver application and approval process. Since many agencies adopt a hybrid approach (in-house and outsourcing combined) for UAS services, it is also essential to identify responsible staff for handling the procurement of UAS consultant services. The manual should also include which FAA rules (i.e., Part 107, Public Aircraft, or both) and the organization that will govern the UAS program.

Key field personnel include the RPIC and supporting VOs who safely execute the mission in compliance with the Part 107 guidelines and other State and local regulations. Several agencies also identified designated Training Officers to ensure oversight and management of initial and recurring training programs of the UAS team members and keep them up to date with evolving requirements. Addressing privacy issues in data collection and retention is another critical issue at the organizational level. It is imperative to collect only the required data for the mission and use it for the intended purpose only. UAS Program Managers or their designated officials ensure the mission complies with policies and guidelines for data privacy. Table 2-3 enumerates the essential characteristics of the UAS team members of the New England DOTs as published in their existing guidelines.

Table 2-3. UAS program's organizational structure for New England DOTs.

UAS Team members	VT	ME	CT	MA	RI	NH
Type of UAS Program	In-house and individual	In-house and individual	In-house and individual	In-house shared service. See Note 1 following the table.	In-house and individual	In-house and individual
Oversight and Direction from Agency	Director of Operations	Chief Engineer	Assistant Chief Engineer (Bureau of Engineer and Construction)	Aeronautics Administrator, MassDOT Aeronautics Division	Policy Director	Commissioner/ Director of Aeronautics
Program Lead	UAS Program Manager	UAS Program Coordinator	UAS Program Coordinator	Aeronautics Administrator and MassDOT Drone Program leadership personnel	NA	Commissioner/ Director of Aeronautics
Designated UAS Committee/ Working Group	Same as the core UAS team members	Same as the core UAS team members	Core UAS team members and additional members from use case departments	A nine-member Drone Policy Steering Committee with administrator and eight outside members	NA	NA
Designated Procurement Offices for In-house Equipment/ Systems	Not identified explicitly	Creative Services, Maintenance Division, Project development	Not identified explicitly	Rolling procurement for UAS services on Commonwealth COMMBUYS system	Not identified explicitly	Not identified explicitly
Designated List of In-house RPICs	Identified	Not identified explicitly	Not identified explicitly	List maintained by UAS Operational Program Manager	Not identified explicitly	Not identified explicitly
Designated List of In-house VOs	Identified	Not identified explicitly	Not identified explicitly	List maintained by UAS Operational Program Manager	Not identified explicitly	Not identified explicitly
Designated Training Personnel	Training Officer	Designated to Program Lead	Designated to Program Lead	Designated to Program Lead	Designated to Program Lead	Designated to Program Lead

NA=Not available

Note 1: In-house shared service supporting MassDOT, the Massachusetts Bay Transportation Authority (MBTA), and other state agencies. Multi-modal support for Aeronautics, Highway, and Rail and Transit, including emergency response team.

2.1.1 *Contracting Procedures*

When establishing an organizational structure for UAS, it is helpful to understand the program's strengths and weaknesses to determine if third party services may be necessary to supplement the in-house program. Most UAS programs find it beneficial to have an in-house program and access to outside assistance through a UAS pool or consultant as needed. Having a pool of qualified consultants can provide resources for additional staffing, advanced missions when specific expertise is needed, or when it may be cost-prohibitive to purchase a needed sensor or resource for a one-time project. When hiring a consultant to supplement a program, it is important to consider the following:

- Experience in aircraft platforms. (e.g., multirotor, fixed-wing).
- Advanced experience with sensors. (e.g., multispectral, hyperspectral, thermal, lidar,[2] magnetometer).
- Compliance with 14 CFR Part 107.
- Experience applying for and obtaining FAA COAs for operations.
- Amount of flight hours in the corresponding platform/sensor.
- Procedures for risk management and mitigation.
- Safety record for UAS (e.g., incidents within the last 5 years).
- Training and proficiency protocols for pilots.
- Appropriate liability insurance coverage for the operation.
    - Typically, $1 million for small projects and $5 million+ for more extensive projects with higher risk are suggested minimums.
- Expertise. (e.g., flight services, data services, or both).
    - If data services are offered, does the deliverable integrate with the company's existing software platforms or needs?
- Mobilization times/cost to be on-site.

2.2. PERSONNEL TRAINING REQUIREMENTS

Field crews operating UAS for transportation applications require skilled personnel who understand and adhere to the various facets that influence a successful mission, including applicable regulations, airspace, weather, emergency procedures, communication protocols, and the flight's specific objectives. For this reason, RPICs need to be FAA Part 107 certified and authorized to fly sUAS. Several UAS programs have mandated additional training programs, both initial and recurrent, to maintain pilots' skills. This process may include a flight test and written exam to demonstrate a strong understanding of the State agency's UAS policy, flight

[2] Note that *lidar* is sometimes referred to as LiDAR, LIDAR, LADAR, or laser scanning, which mostly refer to the same technology. The format *lidar* is adopted for this report since it is the predominant convention used in the industry.

planning, emergency, and risk assessment procedures. Additional flight tests or maneuvers may be required, especially for complex missions involving night operations, flights over people, constrained spaces, and controlled airspace. VOs are not generally required to have mandatory certification or training requirements. However, familiarity with the UAS system for the mission communication protocols (Air Traffic Control and radio communication) is often required.

New England DOTs have varying requirements for training programs and personnel qualifications to fly UAS for transportation applications. Table 2-4 summarizes the salient characteristics of the training program of the New England DOTs as summarized in their SOP/policy manuals.

Table 2-4. UAs program's training requirements for New England DOTs.

Training Requirements	VT	ME	CT	MA	RI	NH
Mandatory Part 107 Certification for RPIC	Yes	Yes	Yes	Yes	Yes	Yes
Agency-specific Training and Flight Requirements (RPIC)	SOP includes initial training, recurrent training, and recertification (24 months). Additional flight currencies within the prior 60 days for RPIC.	SOP includes annual and recurrent training programs.	SOP includes pilot eligibility training requirements. Additional proficiency training within 90 days.	Developed internal training curriculum, qualification standards (beyond Part 107), and checkout process for new RPICs	NA	NA
Agency-specific Training and Flight Requirements (VO)	No mandatory training—endorsement of UAS Program Manager required.	No mandatory training—recommended to attend annual training of the RPIC.	No mandatory training—will be required to fill out UAS inventory and preventive maintenance inspection form.	Developed training and track protocols for VO	NA	NA

NA=Not available

2.3. SAFETY MANAGEMENT AND OPERATIONAL RISK ASSESSMENT

Identifying and mitigating known safety risks early in a UAS project is essential to ensure smoother execution across all phases, including flight operations, data collection, and post-processing. FAA's Safety Management System for Voluntary Program outlines multiple dimensions to an effective safety management system that includes a safety policy, safety risk management, safety assurance, and a culture of safety promotion. At the strategic level, agencies often have an overarching safety policy that emphasizes their vision and commitment to safety and identifies responsible personnel for safety at the office and in the field.

Prior to mission approval, many agencies often necessitate a variant of a project/mission risk assessment process that considers several key issues, including airspace, anticipated site conditions (e.g., temperature, humidity, wind speed, traffic conditions), aircraft platform, sensor payloads checklists, insurance, and any local regulations and permitting requirements. Evaluating the mission's risk against these parameters ensures a timely understanding of potential hazards and the ability to devise mitigation strategies to efficiently manage the risk before the mission moves to the field.

Approval is often required from the UAS Program Manager (or the designee) before the operation takes place. Safety assurance consists of mechanisms to enhance the predictability of the mission's success while accounting for its uncertainties (e.g., insurance policies). Furthermore, operational risk assessments (ORAs) should become an integral part of a UAS operations manual beyond addressing safety factors. Existing ORA frameworks such as Joint Association for Rulemaking of Unmanned Systems (JARUS) guidelines for Specific Operational Risk Assessment (SORA) are largely sufficient. However, more advanced operations will require additional effort (JARUS, 2019), (ASTM F3178-16, 2016). JARUS guidelines provide risk mitigation not associated with safety, including property, privacy, security, and environmental risks, as described below.

- **Property:** To encourage UAS operators to follow proper rules for operations, authorities can implement measures such as restricting operations over private property, requiring notification of flight operations, and requiring some form of insurance to operate a UAS over the property.
- **Privacy:** A common feature of sUAS is a camera (still imagery or video) payload with either onboard storage or the ability to stream the content to the operator or third party. This means of surveillance is a disrupting factor to any real or perceived sense of privacy. Regulations can manage this risk to privacy from UAS operations via operational limitations, limitations on design, or in extreme instances, outright bans on UAS usage.
- **Security:** These are risks associated with motives of deliberate, malicious actors who intend to cause harm to persons or property by controlled flight crash landing, through deliberate interference/distraction (e.g., the distraction of motor vehicle operators), or through carriage and dispatch of harmful items (e.g., munitions, chemicals). There are also potential threats related to a third-party takeover of a UAS (e.g., cyber threats) where control of the UAS is either temporarily or permanently taken from the remote pilot. An expected outcome of this event would be the loss of the UAS. An additional risk is that a UAS that was overtaken could be used to purposefully crash into people/property on the ground or other aircraft and airspace users.
- **Environmental:** The agency may desire to protect sensitive and fragile local areas from ambient noise or other emissions created by UAS operations. Environmental strategies may also look to protect against ambient noise or emissions but instead target

comprehensive approaches. These environmental risks may be managed by restrictions and/or design requirements to contain noise or emissions.

Table 2-5 compares the safety management system and ORA guidelines of the New England State DOTs.

Table 2-5. UAS program's safety management for New England State DOTs.

Safety Management	VT	ME	CT	MA	RI	NH
Safety Policy Statements	Safety statement in SOP.	Safety policy in SOP.	Safety policies are indirect in SOP (e.g., checklists).	Overarching Aviation Safety Management System integrated from flight planning through execution. Compliance with established ground safety MassDOT and MBTA protocols.	NA	Safety policies are indirect in the Directive.
Safety Risk Management	SOP includes comprehensive safety management plan with all the key components, including training.	SOP includes mentions of safety responsibilities and training.	SOP includes office-level checklists for safety.	SOP includes comprehensive safety management plan with all the key components, including training	NA	NA
Safety Assurance	Agency has insurance to cover indemnification for UAS operations.	Agency requires third-party operators on UAS missions to get insurance.	Agency requires insurance for UAS operators on missions; has detailed requirements outlined in SOP.	NA	NA	NA
Operational Risk Assessment	Includes consideration for data retention and privacy and has responsible personnel to manage right	Has limited guidelines for managing ORA risks.	Has limited guidelines for managing ORA risks.	Comprehensive risk assessment procedures to identify, mitigate, record and report.	NA	NA

Safety Management	VT	ME	CT	MA	RI	NH
	of entry to non-VTrans space for missions.					

NA=Not available

2.4. PRE-FLIGHT PLANNING AND ON-SITE RISK ASSESSMENT

Pre-flight planning is the first operational phase of a proposed UAS mission. It comprises planning activities required in the office and on-site to ensure safe flight operations and compliance with Federal, State, and local regulatory requirements. Establishing the mission objectives at this stage is critical to ensure appropriate aircraft and support systems are selected and required staff is identified and engaged. The process often involves formally requesting a mission and obtaining approval from the UAS Program Manager. Most of the agencies recommend including a flight plan in the approval process that provides a general description of the project and a map showing the project location and details of the UAS operating area (including the takeoff location, the complete flight path, and landing locations). The pre-flight planning process also includes clearing checklists that correspond to a complete inspection of physical equipment, maintenance records, weather considerations, battery requirements, charging capabilities, and communication checks. Finally, an on-site risk assessment is often carried out to evaluate any potential safety issues that may arise during the mission and develop suitable mitigation strategies. The RPIC is generally responsible for performing this task. The on-site risk assessment usually focuses on an examination of the airspace, proximity to airports, weather, compliance with FAA regulations, project-specific characteristics (such as obstacles, traffic volume, and speed), and any site-specific constraints. Another important consideration is a flight crew self-assessment of personal health that could affect mission success.

Table 2-6 compares the existing guidelines in the SOPs of New England State DOTs regarding pre-flight planning. A sample of UAS flight plans and pre-flight checklists are provided in Appendices 6.2–6.4.

Table 2-6. UAS program's pre-flight planning guidelines for New England State DOTs.

Project Risk Assessment	VT	ME	CT	MA	RI	NH
Mission Request Form	Required as part of pre-mission planning—includes mission details and a location map.	No formal request form is available in SOP—UAS support request required.	No formal request form is available—has detailed consultant procedure to obtain permission for UAS mission.	Detailed workflows in place. See Note 1 following the table.	NA	No direct procedures available.

Project Risk Assessment	VT	ME	CT	MA	RI	NH
Pre-flight Planning Components	• Flight request form • Flight-risk assessment • Weather checklist • Site-specific considerations • Inspection checklist	• Weather checklist • Planning • Pre-flight briefing • Inspection/ maintenance • Checklist	• Planning • Inspection • Weather • Pre-flight checklist	Formal procedures for risk assessment including: • Weather • Site specific considerations • Equipment condition and selection • Personnel considerations (e.g., currency or task proficiency).	NA	NA
On-site Risk Assessment	Flight Risk Assessment (FRA) under development—example information available in SOP; includes consideration for crew's personal health.	No specific procedures/ checklists provided for on-site risk assessment—SOP mentions adherence to the pre-flight checklist (safety).	No specific procedures/ checklist provided for on-site risk assessment—SOP mentions adherence to the pre-flight checklist (safety).	Formal procedures including checklist examining real time site risks including: • Weather • Terrain • Environment • Personnel • Currency • Health and Readiness	NA	NA

NA=Not available

Note 1: MassDOT detailed workflow for requesting, planning, authorizing, and executing a UAS mission has been developed to track all UAS activities. On-line mission request form developed for use by personnel with any state agency. Request automatically sent to UAS Operational Program Manager.

2.5. FLIGHT OPERATIONS – DURING AND POST-FLIGHT

Successful flight operations include evaluations beginning with pre-flight planning, an on-site risk assessment, and a pre-flight briefing by the RPIC to the flight crew. The pre-flight briefing happens on the day of the operation. It typically focuses on reviewing the mission details, checklists, roles and responsibilities of the personnel, and analyzing anticipated safety hazards and potential mitigation strategies. Subsequently, final preparations for the flight are performed according to the operation's specific requirements, which include:

- Traffic control measures and site layout, including establishing ground control points [GCPs] and checkpoints.
- Setting up communication equipment.
- If required, authorization, notification, and flight coordination. (e.g., Low Altitude Authorization and Notification Capability [LAANC], Air Traffic Control, medical helicopter dispatch, airport managers, and property owners.)
- Pre-flight aircraft inspection according to manufacturer specifications to verify the proper functioning of the systems.
- A final inspection to identify obstacles or obstructions that may impact the flight operation.
- Inspection of take-off and landing zones and designation of an alternate location in the event of an emergency.
- Monitoring aviation band radio for air traffic in the vicinity if the operation is within 10 miles of an airport.

Several transportation agencies then adopt a variant of the following steps to guide the flight operations procedures while in the field (Vermont Agency of Transportation, 2020), (Virginia Department of Transportation, 2019).

Prior to aircraft takeoff:

- The RPIC and VO take their positions and report their status as “Ready.”
- The RPIC ensures the “Home Point” and “Return to Home” function is set correctly and verified for the current mission.
- The VO scans the project area for hazards and concerns and communicates potential problems to the RPIC.
- The RPIC announces “Takeoff” to the crew and observers, and the mission begins.

During the flight:

- The RPIC and VO remain in constant contact during the duration of the mission.
- The VO and other UAS crew help the RPIC achieve the pre-determined mission goals safely and efficiently. Several flight parameters are continuously monitored, including climb rate, altitude, speed, flight path, weather (wind and temperature), battery status, radio connection strength, and overall system health.
- The RPIC announces “Landing” to the flight crew and observers.
- The RPIC examines the landing area for any potential hazards or emerging situations and announces the aircraft is on final approach for landing. If necessary, the RPIC alerts the crew for a “go-around” procedure.

- After landing the aircraft safely on the planned landing area, the aircraft, control, and communications equipment are powered down, removed from the landing area, and stowed appropriately. The RPIC indicates the conclusion of the mission.

After the flight, the following steps occur:

- A post-flight aircraft inspection is conducted identify any malfunctions or damage to the airframe or sensors.
- Once the mission concludes and the project site is secured, the RPIC issues a post-flight briefing. The purpose is to review the mission's events, discuss successes and problems, and suggest future improvements.
- The data collected using the onboard sensor payloads during the flight are transmitted to a backup storage device for data processing.
- The data are field verified to check for any inconsistencies or issues (e.g., gaps in mapping, blurry images, and overexposed images). If problems are found, they can be remedied while in the field.

Table 2-7 compares the flight operation procedures outlined in the SOPs of the New England State DOTs. A flight checklist for the operations phase is also provided in Appendix 6.4.

Table 2-7. UAS program's flight operations for New England State DOTs.

Flight Operations	VT	ME	CT	MA	RI	NH
Pre-flight Briefing	A detailed procedure, including a checklist, is outlined in the SOP.	Pre-flight planning and checklists provide implicit guidance on pre-flight briefing.	Detailed pre-flight office and field checklists are provided; filing the flight log form is recommended.	Detailed briefing of mission overview, risks, and personnel roles and responsibilities.	NA	No direct procedures available.
Flight Operation–Parameter Controls and Monitoring	Summary steps available for actions to be taken by RPIC and VO in ensuring mission compliance.	Explicit procedures are not available in SOP.	Summary steps and flight operations checklist available.	Personnel responsibilities and abnormal procedures clearly laid out in briefing and in SOPs.	NA	NA

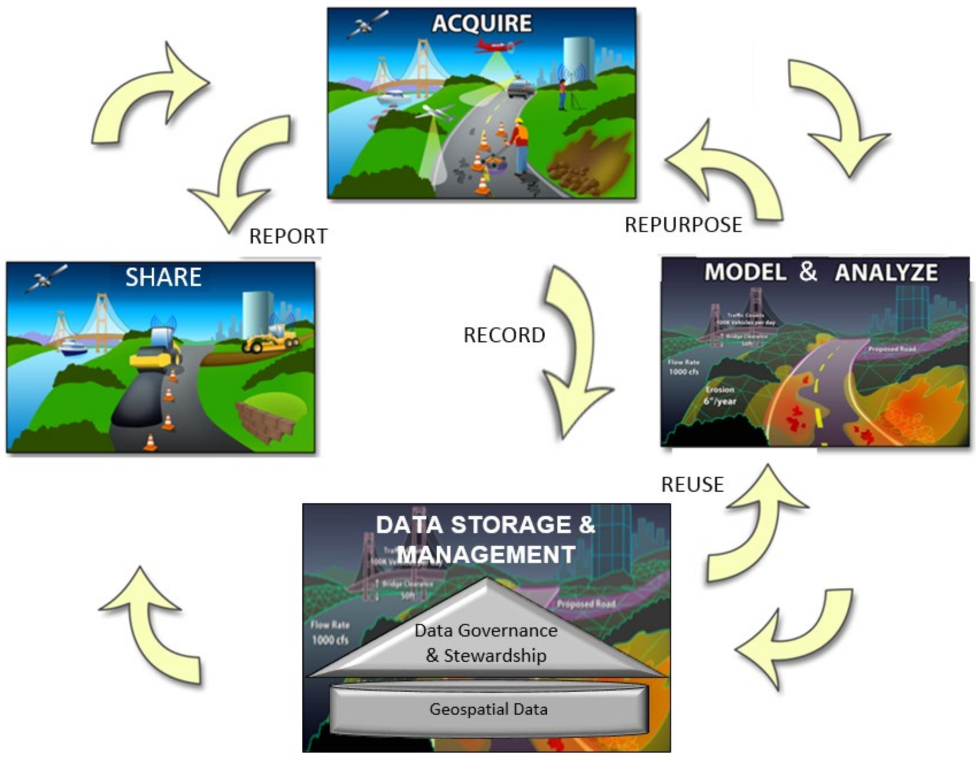
Flight Operations	VT	ME	CT	MA	RI	NH
Post-flight Operation Procedures	A checklist of activities to be performed is included in the SOP and includes a post-flight briefing.	No specific procedures/checklist provided for post-flight operations.	A checklist of activities to be performed is included in the SOP (includes post-flight briefing, mission log forms).	A checklist of activities to be performed is include in the SOP and includes a post flight briefing.	NA	NA

NA=Not available

2.6. DATA MANAGEMENT

Each UAS mission generates a considerable amount of imagery, video data, and vital information on flight performance and characteristics, including data on weather, telemetry, traffic, aircraft, and crew performance that has been recorded and can be used to support future requirements. As the amount and type of data expand, data management policies to manage the information life cycle gain significance at an organizational level. Agencies often align their data management guidelines with existing enterprise-wide data systems and governance policies that define data quality processes and standards, provide funding recommendations, and establish communication protocols concerning data use by various departments within the agency. A well-defined data management system should entail guidelines for collecting, analyzing, archiving, transmitting/storing, and protecting the data. New tools and workflows are dissolving traditional data life-cycle segments into more effective solutions (Figure 2-2) (Mallela et al., 2018). Determining a viable management solution for the entire life cycle of the data and disseminating its use to multiple parties can further increase the value and return on investment for organizations. Sharing can also help justify the large data sets created by allowing multiple uses across the organization from the same data sets.

Figure 2-2. Illustration. Modified data life cycle.



Source: (Mallela et al., 2018)

Establishing a holistic data management framework enables the organization to have a reliable and repeatable procedure that can be used for multiple missions. Key components are described below.

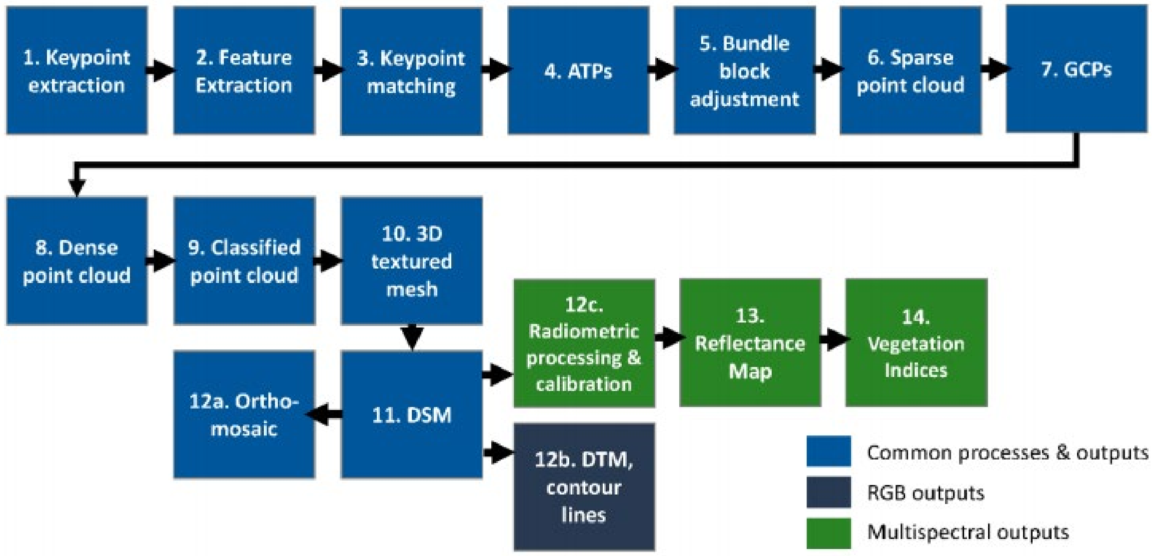
2.6.1 Data Processing

The most common method of post-processing aerial images for surveying or mapping is to stitch them together using commercially available software. While the specific techniques used for data processing may vary depending on the software solutions used, it is essential to identify general stages in processing UAS data and incorporate any specific recommendations for transportation use cases. A summary of the workflow is presented below (Pricope et al., 2019).

- **Global Navigation Satellite System (GNSS) Post-processing:** During data acquisition, the images are geotagged with coordinates from the Unmanned Aerial Vehicle's (UAV) internal GNSS system. Aircraft may have various quality GNSS sensors, including consumer-grade, Real-time Kinematic (RTK), and Post-processing Kinematic (PPK). Consumer-grade GNSS must be supplemented with GCPs to improve the residuals. In addition to GCPs, RTK or PPK can also be used to improve the accuracy. PPK is usually preferred because it has less potential for initialization loss during the flight collection from radio interference. A statewide Continuously Operating Reference Station (CORS) network, such as MassDOT MaCORS can be used for RTK and PPK data to eliminate the need for an on-site GNSS base station to collect static observations. Most of the available software solutions provide algorithmic filters that take in raw data, GCPs, and survey-grade global positioning system (GPS) coordinates (if used in UAV) and output a report with the final deliverable.

- **Photogrammetric Software Processing:** Photogrammetric software can be used to process the imagery to produce deliverables that may include three-dimensional (3D) point clouds, orthomosaic, and Digital Surface Model (DSM), among others. Some popular commercial-off-the-shelf platforms use structure-from-motion to estimate the 3D structure of objects from multiple two-dimensional offset image sequences. The state-of-the-art computer vision algorithm that replaces the conventional stereo-scoping photogrammetry technique is briefly described below and illustrated in Figure 2-3.
    - The first step involves extracting key points and matching them between images and extracting features. Key points are distinct spatial locations that are invariant to object rotation or scaling. The detected key points are automatically matched between multiple images to assist feature extraction. Several algorithms exist to automatically perform this task with minimal assumptions, including Scale-Invariant Feature Transform, Speeded-Up Robust Features, and Binary Robust Invariant Scalable Key Points. Often, the user can customize the key point image scale in the software to specify the scale at which key points are extracted with respect to the raw/original image scale. It is recommended to keep this value above the raw image scale (>1) to ensure more key points are extracted and a higher degree of confidence in the output.
    - In the next step, automatic tie points are identified from the key points and are matched between the images to allow the computation to transition from image space to object space. Images are calibrated in this space using overlapping images (with corrected coordinates), tie-points, and applicable GCPs. This process is also called aero-triangulation or Bundle Block Adjustment. The generated output is usually a Low-Density Point Cloud that is scaled to produce a High-Density Point Cloud. This scale can be customized by the user (1/8-1), and it defines the relation to the original image size at which additional 3D points are generated. Finally, the High-Density Point Cloud is used to generate 3D textured mesh, DSM, and an orthomosaic (where each pixel's value is calculated as an average of the pixels in the corresponding original images).

Figure 2-3. Flowchart. Key photogrammetric steps in structure for motion workflows for RGB and multispectral imagery.



Source: (Pricope et al., 2019)

- **Light Detection and Ranging (Lidar) Processing:** Using lidar can be beneficial in areas with vegetation, reflective surfaces, or areas with shadows where using point clouds derived from photogrammetry can produce undesirable results. Both lidar and structure for motion software can produce point clouds; however, lidar generally takes less time to process a point cloud from the raw data to create a deliverable. The steps for lidar processing are summarized below for a PPK process:
    - Check coverage on flight lines to ensure proper overlap and density of the lidar data for the intended purpose.
    - Process flight lines with the raw satellite navigation data from the base station or CORS network to improve the flight lines' geolocation accuracy.
    - Use software to calculate and correct misalignment in flight line values to reduce noise and correct XYZ location errors.
    - Classify point cloud according to the deliverable requirements.
    - Create a final deliverable consisting of the classified point cloud, DSM, or another suitable 3D model format.
- **Quality Control:** The final deliverables are often validated using quality control checks based on the agency's acceptance requirements for photogrammetry/UAS based products. The horizontal and vertical accuracy of the deliverables is typically used for this purpose. A general recommendation is to set the threshold for 95 percent accuracy, which means that 95 percent of the data's checked samples should have errors less than the desired threshold. For example, Montana DOT used a 95 percent vertical accuracy goal of 0.30 feet for some of its recent projects (Montana Department of Transportation, 2017).

Montana DOT also noted common ways to enhance the accuracy of data collection, including collecting imagery from a lower altitude (decreased ground sampling distance) and increasing image overlap (%). These parameters can be customized as inputs during flight planning. Figure 2-4 provides an example of a quality control sheet that Utah DOT uses for UAS and survey quality control.

Figure 2-4. Worksheet. Quality control worksheet example.

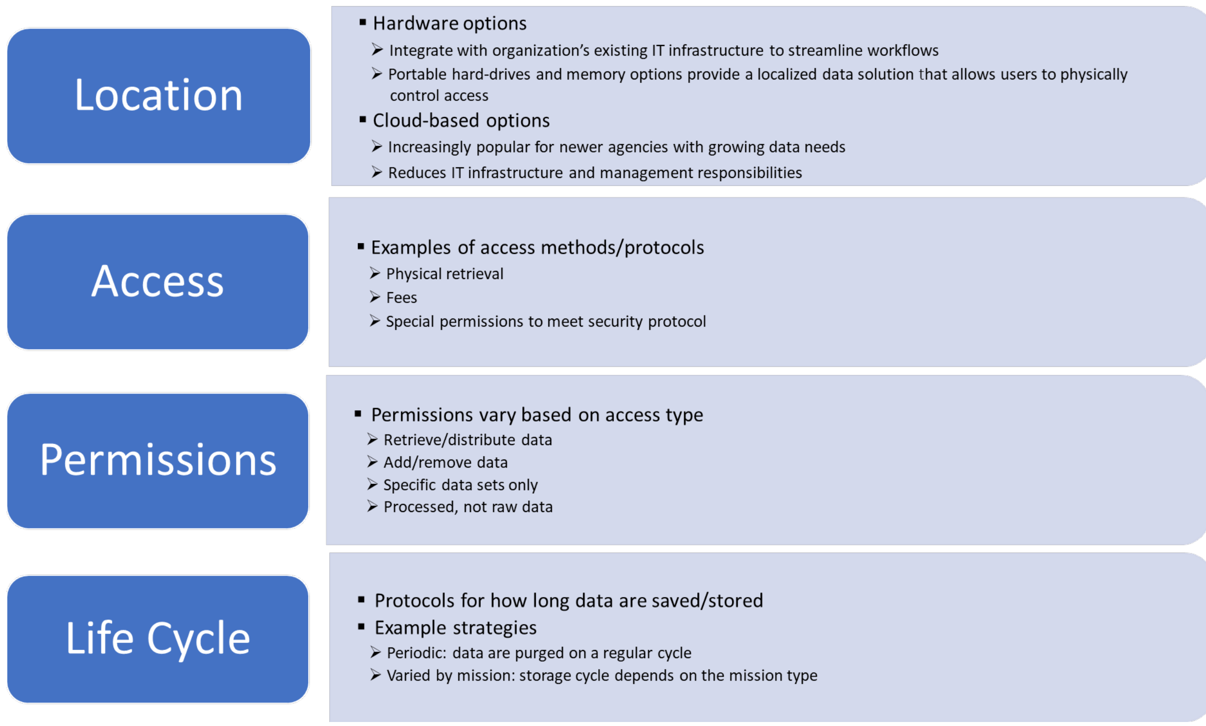
	POINT			ELEVATION	NORTHING	EASTING	ELEVATION			ERROR
71	1151			3788.06	113741.25	572386.58	3788.06			0.00
72	1152			3787.84	113741.41	572375.89	3787.90			0.05
73	1154			3787.57	113720.26	572355.68	3787.70			0.13
74	1155			3787.33	113708.19	572340.29	3787.34			0.00
75	1156			3787.29	113700.01	572336.63	3787.26			-0.03
76	1164			3786.48	113648.18	572274.96	3786.47			-0.02
77	1165			3786.46	113648.62	572264.49	3786.44			-0.03
78	1166			3786.36	113632.89	572253.04	3786.29			-0.07
79	1167			3786.24	113621.83	572236.72	3786.23			-0.01
80	1174			3785.55	113559.50	572167.23	3785.65			0.10
81	1175			3785.56	113563.69	572154.37	3785.62			0.05
82	1176			3785.51	113552.82	572149.52	3785.48			-0.03
83	1177			3785.42	113539.87	572140.59	3785.37			-0.05
84	1179			3785.27	113519.68	572114.83	3785.27			0.01
85	1180			3785.20	113519.12	572105.90	3785.29			0.09
86	1181			3785.15	113525.44	572099.48	3785.24			0.09
87	Number Chk Pnts									81
88	Mean Error (us)									0.01
89	Standard Deviation (us)									0.04
90	RMSE (us) - RMSEx, RMSEy, RMSEz									0.04
91	RMSEr (us) - Combined Horizontal RMSE									
92	H Accuracy @ 95%									
93	V Accuracy @ 95%							0.08		

Credit: Utah Department of Transportation

2.6.2 Data Storage and Security

The four primary data and storage security elements are establishing location needs, access needs, permissions protocols, and life-cycle protocols based on the organization's data needs (Snyder et al., 2018). The key consideration for determining the location is deciding between hardware or cloud-based storage options. Location selection depends on the current capabilities and future goals for the organization and the UAS program as described in Figure 2-5. Access methods/protocols vary based on the location selection and security protocols. Well-defined permissions rules (e.g., who can access the data and what they can do with the data) based on roles and qualifications are essential for audit and security purposes. Organizations should develop a well-defined life cycle to anticipate data needs as they grow within an organization. A plan is beneficial to determine how long data should be retained once stored based on their purpose; the plan should balance maintaining essential data and ensuring obsolete data are not unnecessarily taking up storage space.

Figure 2-5. Illustration. Summary of key considerations for data management and security.



Source: (Snyder et al., 2018)

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 data storage layers and security layers. If the data management protocols are not well established in data collection, data quantities can quickly become overwhelming and disorganized. The agency may already have a data management policy that can be adapted to suit UAS data integration.

2.6.3 Data Transmittal, Retention, and Privacy

Another significant issue is related to data retention and privacy. As the technology capabilities continue to evolve, opportunities to collect a variety of data to support various use cases increase. The flight crew needs to ensure only the data necessary for the mission are collected, and any information inadvertently collected be discarded. It is also the responsibility of the flight crew and the broader UAS team to ensure that the mission complies with any governing Federal, State, or local regulations on privacy. All the digital data collected using the UAS are then retained, transmitted, or archived according to the agency's data retention policies. Table 2-8 compares the post-flight data processing guidelines of the New England State DOTs.

Table 2-8. Data management guidelines of New England State DOTs.

Flight Operations	VT	ME	CT	MA	RI	NH
Enterprise Data Systems and Governance	No specific guidelines available at the agency level.	Agency has detailed systems and governance document that identifies critical data sources across departments and lays out policy guidelines for communication, funding, and sharing.	No specific guidelines available at the agency level.	Dedicated data and cybersecurity specialists on Drone Program team, working with MassDOT IT and the Massachusetts Executive Office of Technology Services and Security to meet broad data needs using enterprise solutions.	No specific guidelines available at the agency level.	No specific guidelines available at the agency level.
Data Processing Workflow	SOP does not include mission-specific or general guidelines on data processing—has limited guidelines to support analysis.	SOP does not include mission-specific or general guidelines on data processing.	SOP does not include mission-specific or general guidelines on data processing—has limited guidelines to support analysis.	See Note 1.	SOP does not include mission-specific or general guidelines on data processing.	SOP does not include mission-specific or general guidelines on data processing.
Data Storage and Security Guidelines	Recommends transmitting the collected data within 48 hours for data processing.	No specific guidelines available for data transmittal or analysis beyond post-flight checklist.	Generally, recommends transferring the data as necessary to a backup storage device.	Follow enterprise data storage and security guidelines	NA	NA

Flight Operations	VT	ME	CT	MA	RI	NH
Data Retention and Privacy Guidelines	The agency retains only the data collected on its mission. Has privacy officer overseeing the compliance of the UAS program and manages the right of entry requirements for the missions that fall outside the authority of the agency.	UAS policy refers to the SOP for guidelines on data retention and privacy. Data retention practices shall adhere to the guidelines as described in Maine DOT APM No. 121.	SOP states that digitally recorded data and media recorded by a UAS will be handled and stored in a manner acceptable to the department.	See Note 2.	NA	NA

NA=Not available

Note 1: MassDOT developed data workflow with strong emphasis on integrating data indexing, storage and analysis tools. Securely store collected imagery, analyze using different tool suites, and disseminate to the end use using tools such as ArcGIS. Continuing to develop data solutions using best practices include Agile development and DevOps.

Note 2: MassDOT Data Retention and Privacy Guidelines includes the following information: Follow public records retention requirements. Per UAS policy, use of UAS must be conducted in a manner designed to minimize the risk of unintentional invasions to privacy and to address any such unintentional invasions quickly and effectively as a precautionary measure, MassDOT will not use UAS to intentionally collect images over private property without prior authorization from the Secretary of Transportation or express permission from the property owner.

2.7. UAS EMERGENCY PROCEDURES

SOPs are necessary to establish the steps to be followed in an emergency. In general, an accident report is recorded to capture the emergency details, and when necessary, the event is also reported to the FAA Regional Operations Center (see section 2.9). Several agencies cover the following emergency events in their manuals (Virginia Department of Transportation, 2019). An emergency procedure checklist is provided in Appendix 6.5.

- **Total Loss of Aircraft Power:** This case represents a total battery failure (or power failure in cases of a tethered aircraft). In such situations, the rate of descent may vary depending on the type of aircraft (rotary-wing aircraft may have a more rapid descent than fixed-wing aircraft). The RPIC and VO announce the emergency and take necessary steps to prevent any cascading sequence of events, including calling 911 if required to control the situation. After the crash, the flight crew secures the site, mitigates any unexpected events (including fluid leaks, fire), and executes the Downed Aircraft Recovery Plan (DARP) procedure.

- **Partial Loss of Aircraft Power:** This case is less severe than a total loss of power. Nonetheless, it is essential for the RPIC to expeditiously announce the emergency and land the aircraft in a designated emergency landing zone for the mission or a safe ditching area. Once the aircraft is powered down, the situation is assessed for any mitigation plans necessary, and a DARP gets executed.
- **Airspace Encroachment:** This situation occurs when a manned aircraft or another UAS has encroached the planned flight path. The RPIC announces this emergency to the crew and, with their help, takes the appropriate course of action (immediate evasion, landing, or hovering/loitering) until the hazard has passed.
- **Loss of Control of the Aircraft Including Sustained and Transient Loss of Control:** The RPIC announces the emergency if the communication between the aircraft and RPIC (C2 link) is lost. The "return to home" feature should automatically enable the UAS aircraft to return to the project starting location; the RPIC attempts to do the same if the control is established. Return to home should not be used if the aircraft has lost connection with satellites as this could create a fly-away situation. If communication is reestablished and the aircraft is in visual line of sight, the pilot should attempt to fly the aircraft back to the home location manually. If this step fails, the aircraft is considered to be in "fly-away" mode, and the corresponding emergency procedures should apply.
- **Erratic Aircraft Behavior:** If the aircraft exhibits sustained or transient erratic behavior, the RPIC announces the emergency to the crew and attempts to land the aircraft immediately in an emergency landing area. If this step fails, the aircraft is considered to be in "fly-away" mode, and the corresponding emergency procedures should apply. Failure of systems including C2, GPS, or the Ground Control System can also cause aircraft to exhibit erratic behavior.
- **Aircraft Fly-away:** This case represents a situation that can unfold into the most impactful emergency. The RPIC immediately announces the total loss of control to the crew and attempts to resolve the situation by performing the following actions:
    - Inspect the control device for power and connection strength.
    - Check the response of manual flight controls to try to regain positive control of the aircraft.
    - If the above steps fail, enable the "return to home" function of the aircraft.
    - Subsequently, if the "return to home" function fails, record the flight parameters (e.g., heading, altitude, speed) to evaluate possible intrusion into areas that would have hazardous consequences (e.g., controlled airspace, traffic, unprotected people, protected infrastructure facilities).
    - Pursue an appropriate course of action, including contacting Air Traffic Control or 911 to manage the emergency if necessary.
    - Use flight software, once the emergency response is completed, to find the last known location of UAS to initiate the DARP for recovery.

- **Bird or Fixed Object Strikes:** A bird strike can cause aircraft to lose control and crash. Depending on the extent of damage to the systems, either a total loss or partial loss of control should be announced, and an appropriate course of action should be taken.
- **Outside Interference with the Flight Crew:** If interference is noted from private individuals, the RPIC announces the emergency to the crew, evaluates the potential situation, and takes an appropriate course of action, including landing the aircraft and calling 911 for immediate assistance as required. Having a flight crew member dedicated to addressing outside distractions can benefit a sterile flight environment and safe operation.
- **Nearby or Collocated Emergency Response Activities:** If an emergency occurs in the flight area perimeters (e.g., vehicular accidents or hazardous material spills), the RPIC announces the emergency immediately to the crew and attempts to land the aircraft. All operations are halted until the emergency is resolved.

Some of the existing New England State DOT guidelines cover emergencies, including describing the event and potential rescue actions in case of each event. VTrans guidelines cover most of the described events in detail and identify corrective actions. Connecticut and Maine enumerate potential emergencies of concern for their UAS crew on-site. New Hampshire and Massachusetts offer general directives and policies that point to FAA regulations and safety instructions to manage emergencies.

2.8. DOWNED AIRCRAFT RECOVERY PLAN

The DARP represents the SOP that the flight crew needs to follow after an aircraft has crash-landed. The RPIC is responsible for implementing the DARP requirement under this area (which is generally available as a checklist). In general, no recovery activities are allowed before the emergency response has concluded. The RPIC and the flight crew identify the location of the crash landing and seek necessary permission from concerned parties before entering the area for recovery. This may include permission from the responsible private owner or government agency that owns the landing area. Assistance from 911 is also sought as required for addressing the emergency.

Once the emergency response has concluded, the RPIC and the crew verify that the aircraft, control, and communication systems are powered off. The site is then secured to recover the aircraft. The necessary data are collected to investigate the crash, including photographs and site logs. An accident report is completed that documents the details of the crash to the best knowledge of the crew. A DARP checklist is provided in Appendix 6.6 of this report for reference.

New England State DOTs have either directly or implicitly included general guidelines to recover an aircraft that has crash landed. VTrans addresses a DARP extensively with all the required steps to be followed. Connecticut mentions emergency procedures and includes general guidelines for recovering an aircraft in its SOP. Maine also includes planning-level guidelines for the RPIC to follow in an emergency to collect an aircraft that has crash landed. New Hampshire and Massachusetts do not directly comment on a DARP but offer general directives and policies that point to FAA regulations and safety instructions to manage emergencies.

2.9. ACCIDENT REPORTING

An accident report is often required when an in-flight emergency occurs or a DARP gets recorded. Several transportation agencies have delineated the required attributes to describe the event's sequence, investigate potential causes behind the crash, and document lessons learned. Operators need to be knowledgeable about the National Transportation Safety Board'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. At a minimum, an accident report is required to include the information described below. It should be submitted to the UAS Program Manager within 10 days after the incident. After the details are verified, the report is also electronically submitted to the FAA Regional Operations Center, per FAA 107.9 requirement as required.

- The date, time, location, and description of the project and the specific operation being conducted when the incident occurred.
- A description of the UAS equipment being used.
- A listing of the flight crew involved in the operation at the time of the incident.
- A listing of any other persons presents at the time of the incident.
- A detailed description of the incident based on the observation of the RPIC and/or crew member witnessing the incident.
- A detailed description of any actions taken by the flight crew.
- A detailed description of any interaction between the flight crew and any other person(s) resulting directly or indirectly due to the incident.

A report to the FAA Regional Operations Center must be submitted within 10 calendar days after the operation if it meets the following criteria:

- Serious injury to any person or any loss of consciousness; or
- Damage to any property, other than the small unmanned aircraft, unless one of the following conditions is satisfied:
  - The cost of repair (including materials and labor) does not exceed $500; or
  - The fair market value of the property does not exceed $500 in the event of a total loss.

An example accident reporting form is included in Appendix 6.7 of this report. Guidelines from New England State DOTs offer procedures to follow while reporting accidents. VTrans mandates the incidents be reported to the UAS Program Manager within 10 days and documents necessary elements to be reported. Connecticut requires reporting the incident to the FAA's Regional Operations Center or the nearest jurisdictional Flight Standards District Office. Maine, New Hampshire, and Massachusetts do not directly address accident reporting but offer general directives and policies that highlight the FAA regulations and safety instructions.

2.10. GUIDELINES FOR OBTAINING WAIVERS

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. Waivers to FAA Part 107 regulations may be required on a case-by-case basis to conduct UAS missions depending on the nature of the operation and on-site constraints. It is important for an agency to include potential guidelines for its in-house team or service provider to facilitate waiver applications.

New England State DOTs' operation manuals mandate compliance with the FAA Part 107 regulations; however, they offer limited guidelines on requesting waivers and potential approaches to enhance chances of approval. In its recent compilation of UAS operational data from the Part 107 application process, FAA indicates that detailed ORAs and technical and managerial countermeasures form the key components of a successful waiver application. The recommendations of FAA for Part 107 waivers were covered in detail in the Task 3 report.

2.11. USE CASE INDICATIONS

While an SOP is practically aligned toward helping the agency implement UAS for many applications, it is also useful to identify potential use cases that UAS can support for routine or unanticipated situations. Agencies should consider incorporating recommendations for plausible UAS applications that can be accomplished, considering their in-house capabilities and overall program maturity. The list of applications can be revised periodically to modify or add more use cases depending on technological advancements, availability of more skilled personnel, and increased acceptance of the UAS at the management level. Factors such as existing UAS fleets, availability of Part 107 certified remote pilots, data processing, and other support systems (either through in-house staff or contracting a service provider) should be used to identify potential applications. Listing the potential use cases in an SOP can support the development and adoption of operational-level guidelines and promote the technology's acceptance and use across the agency's various departments.

New England State DOTs have varying levels of identification and documentation of specific applications that their UAS program can support on a preliminary or sustained basis. MassDOT enumerates its use cases of interest (drone pilot program) in its interim drone policy and highlights documentation of technological capabilities, best practices, and lessons learned to support revisions to existing policies and operational procedures for expansion of its UAS program. Virginia DOT identifies incident and traffic management, infrastructure inspections, and project development and delivery as its applications of interest in its SOP. VTrans has mandated that each UAS flight be discussed with the UAS District Coordinator and a UAS activity subject matter expert within the agency. The discussion will identify acceptance requirements, climatic and environmental conditions, or technology constraints ("use constraints") that might affect the desired objective and final deliverables.

3.0 IMPLEMENTATION PROCEDURES FOR USE CASES

UAS present a viable alternative to successfully collect and process the required data to support various use cases. Developing and periodically revising SOPs is an important step to ensure flight missions are planned and executed systematically with suitable strategies to support operational efficiency and on-site safety. The previous sections of this report review key topics that constitute a UAS operations manual and compare the existing guidelines of the New England State DOTs along these areas.

Meeting the requirements outlined in the topics often streamlines mission planning, flight operations, and subsequent processing associated with multiple applications. Based on information from the previous sections of this report (and the preceding tasks of this project), this section focuses on developing implementation plans for each of the six use cases identified for the project, namely emergency response, public outreach and engagement, bridge inspection, surveying and mapping, construction inspection, and traffic analysis. Table 3-1 provides the list of use cases selected for each New England State DOTs.

Table 3-1. UAS use cases for New England State DOTs for developing implementation plans.

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

The subsequent sections propose implementation procedures that highlight the primary steps involved in supporting an agency's decision to deploy a UAS to support a particular operation and include specific considerations for the chosen application. The existing program maturity of New England State DOTs and their chosen interests were considered in the development of the procedures. Peer agencies were also identified for each of the use cases based on their documented expertise in the literature in deploying UAS for the pertinent application or based on their higher program maturity. Along with the UAS operation manuals, these plans are intended to act as supplementary guidelines to assist New England State DOTs in their decision-making toward selecting UAS and deploying them successfully for data collection and processing for the specified use cases.

3.1. IMPLEMENTATION PROCEDURE FOR EMERGENCY RESPONSE (VTrans)

Emergency response situations can often necessitate rapid data collection amidst a challenging and constrained environment. North Carolina reported ways that UAS were beneficial in response to Hurricane Florence (Ramsey, 2019).

- Providing real-time situational awareness of threats and hazards (public and responder safety).
- Assessing conditions of inaccessible, hazardous, and/or contaminated areas via images and sensors.
- Determining the status of roads and critical infrastructure.
- Providing geospatial references and navigation.
- Monitoring response operations and effectiveness.
- Monitoring the movement of persons, vehicles, resources, and providing security.

Technologies such as UAS have made significant strides in assisting emergency responders and other key stakeholders to access imagery and video data of the impacted areas in a safe, timely, and efficient manner, as addressed in the Task 1 report in detail. Many examples illustrate the benefits of UAS. In Houston, during Hurricane Harvey, UAS was used to perform many crucial tasks to evaluate the damage, which included determining when it was safe to reenter and assisting with search and rescue (Karsten & West, 2018). The Mesa County Sherriff's office found UAS to be an efficient tool that realized significant savings. UAS had a direct operational cost totaling \$3.36 per hour, compared to \$250 to \$600 per hour for a manned aircraft (AUVSI, n.d.). Reducing data collection time has profound impacts on monetary savings and, most importantly, saved lives. When using UAS for emergency response, it is vital to understand the mission's objectives, assess the existing capabilities, and develop a suitable response strategy.

Step 1 – Define Mission Objectives

The first significant step in decision-making is clearly articulating the mission objectives and understanding the data collection scope necessary to assist the emergency response for various natural disasters (including flooding, wildfires, landslides, and other events). The emergency response's objective may include rapid data collection to assist in disaster relief efforts or surveying and reconnaissance efforts to monitor impacted areas, often in real-time using imagery or video data. While UAS technology is suitable for many of these situations, it is essential to evaluate available alternative technologies. Some of the alternative technologies or methods include the following.

- **Aerial surveys using manned aircraft or missions** could be useful for missions that require targeted assistance or data collection and longer flight durations. It is generally not cost-effective compared to other alternatives and is often inadequate for assessing damage extent and severity.

- **Remote sensing satellites** for disaster response is another potential alternative if the impacted area is large, and the objective of the survey is to identify and rescue victims and obtain damage information over an extended period. In the United States, such information comes from the National Oceanic and Atmospheric Administration and commercial providers such as DigitalGlobe, Planet, and Cubesat (Duffy, 2018).

UAS can support the mission individually or in combination with the other alternatives, especially with its expanding capabilities to carry a variety of sensor payloads. Payloads including RGB cameras, lidar, infrared, and multi-spectral sensors are increasingly cost-effective and provide the ability to collect data safely in real-time (livestream) and to the required quality.

Table 3-2 compares alternative technologies based on several performance metrics often considered for selection at this level.

Table 3-2. Alternative Technologies comparison for emergency response.

Technology	Quality of Data	Cost	Safety of Data Collection	Duration
Aerial Survey	Low-moderate	High	High	Longer missions
Remote Sensing Satellites	Moderate-high	Low-moderate	Very high	Longer missions
UAS	Moderate-high	Low-moderate	High	Shorter-medium missions (less than 45 minutes)

Step 2 – Develop System and Staffing Plan

Once an agency decides to deploy a UAS (based on the alignment of mission objectives), the second key step is to engage the necessary resources to support the flight mission from planning to data processing and closeout. This step includes the following.

Team Selection: VTrans has an established UAS program under its Rail and Aviation Bureau that provides an experienced team with a program coordinator, FAA-certified remote pilots, VTrans-trained VOs, airport operation specialists, civil engineers, and a GIS mapping and data processing specialist. It may also be necessary for an emergency response to coordinate with other departments within VTrans and other external stakeholders. VTrans is equipped with an Incident Command System composed of four regional commands that provide an organized hierarchy of command, control, and coordination for emergency response teams with multiple agencies' stakeholders. First responders and law enforcement personnel are used under this structure to facilitate an integrated and effective response. It would be beneficial for the agency to develop hierarchies in SOPs that delineate various authorities' touchpoints in the agency's UAS program and Incident Command System.

System Selection: Emergency response operations typically require UAS platforms that can be deployed quickly in harsh environments. They must be capable of capturing high-quality data with a horizontal accuracy (HA ~ 1 centimeter [cm]) and a minimum GSD (around 2.5 cm) that provides good sampling for decision-making for emergency response. VTrans has four operational drones with comparable specifications and software required for emergency response. The following DJI-related software packages are used to support VTrans UAS operations:

- DJI Go 4 App – flight operations and data collection/sharing.
- DJI Assistant 2 software – manage firmware, calibrate sensors, view flight data, and simulate flights.

VTrans is reported to have transitioned to Pix4D for image processing using photogrammetric techniques. VTrans also uses Microsoft Stream for live streaming footage from drones for emergency response. The agency could consider testing and expanding its fleet to include UAVs connected via cellular networks (instead of a conventional hand-held radio transmitter) to facilitate Beyond Visual Line of Sight (BVLOS) operations and deployment in remote areas. Drones relying on 4G/5G connectivity can travel greater distances, collect quality imagery and video data, and facilitate real-time data transmission for decision-making.

In general, the agency is suitably positioned to perform most of the necessary work in-house unless a mission requires specific skillsets or crew members are not available. However, the agency also noted staff availability as a significant issue during case study interviews. It would be beneficial to develop and validate policy guidelines for the procurement of UAS-services.

Step 3 – Develop Flight Plan and Perform Risk Assessment

With mission objectives clearly established and resources mobilized, the next critical step is to conduct a holistic risk assessment that covers major flight planning activities in both the office and field environments. VTrans' risk assessment checklist is under validation (according to the latest version of the SOP) and includes considerations for weather, crew experience, mission factors, and site-specific considerations (including terrain, traffic, airspace). In general, it would be beneficial for the agency to include a flight plan as part of the risk assessment process with a detailed project map and a description of the project.

For the emergency response use case, it might be relevant to incorporate risks from coordination challenges arising from multiple agencies' involvement. Delineating the risks and responsibilities of individual players in an inter-agency agreement or developing a Common Operating Picture framework would be a practical measure to overcome this issue and mitigate any risks arising at this level. Some of the guidelines in this regard are provided in the Task 3 report.

Step 4 – Obtain Permits and Waivers

Ensuring compliance with Federal, State, and local regulations and assessing the requirements of Part 107 waivers forms the next step in UAS implementation procedure for emergency response. Due to the nature of the operations, deploying UAS for emergency response may require waivers for operating BVLOS (107.31). It may require permission to restrictively operate under controlled airspace, in which case, a LAANC procedure may be leveraged to obtain real-time authorization to operate under this situation, especially if the flight falls under pre-approved zones and altitude (as identified in FAA's UAS Facility Maps). Procedures for these waivers are addressed in the Task 3 report.

VTrans has protocols to facilitate expedited approval for emergency and incident response missions and has established procedures to secure other potential permits. A good working relationship with the FAA was also noted during case study interviews to support the waiver application process. Another notable feature is the presence of a Senior Agency Official to assist in obtaining a right of entry for the missions that fall outside the authority of VTrans.

Step 5 – Obtain Approval and Perform Flight Operations

With all the necessary permits and waivers in place and pre-flight planning procedures complete, the next step is the approval process. VTrans has identified personnel (UAS Program Manager) who authorize the mission. It is also important to consider implications for emergency response arising from collaboration with other external agencies. As discussed earlier (Step 1), it would be beneficial to document in an SOP the appropriate hierarchies if multiple stakeholders are involved in approving the mission.

After the approval process, flight operations are conducted. This stage comprises three phases: site mobilization (pre-operations), flight operations, and data processing. The three phases are described in detail in the Task 3 report with the process maps. A key requirement during the pre-operation stage is conducting an on-site hazard/risk assessment before the RPIC gives the final go-ahead. The UAS operations manual includes guidance for a Flight Risk Assessment (FRA), although it is yet to be validated. Live streaming of imagery or video data becomes vital for emergency response, and VTrans has Microsoft Streams (or other video streaming services) to support this operation. Transitioning to a desktop or cloud-based solution (e.g., Pix4D or other image and point cloud processing service) can also facilitate a holistic workflow, either via desktop or cloud-based processing, and generate the required deliverables to assess or quantify the extent of the damages (e.g., DSMs 3D point clouds, orthomosaics).

Step 6 – Assess Outcomes and Document Lessons Learned

With the UAS operations complete, the quality of the data is assessed against the capabilities to make decisions for the situation. Metrics from UAS operation such as accuracy, point density, GSD, resolution, and the data transmission rate (for livestreamed data) provide useful information on gaps in technologies or support systems used during the process. Any refinements necessary to an emergency response's integrated organizational structure can also be inferred based on the response operations' effectiveness over time. Any technological, organizational, or policy guidelines noted over multiple missions can be leveraged to develop suitable refinements to the existing operations manual. Peer agencies can also play a vital role in sharing lessons learned and best practices to enhance operational efficiency. Some of the peer agencies to consider for emergency response include Virginia DOT, Ohio DOT, Utah DOT, Alabama DOT, and North Carolina DOT.

Table 3-3 summarizes the procedural requirements highlighted in the six steps presented in the section with the key questions to support decision-making for using UAS for emergency response missions.

Table 3-3. Implementation procedure summary for emergency response (VTrans).

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions For Decision to Support UAS Deployment
Define Mission Objectives	VTrans' Operations Manual provides detailed guidelines with 9 of the 11 programmatic topics covered.	Guidelines can be strengthened for waiver applications (covered under Task 3) and use case indications.	• Are there alternative technologies to support emergency response? • Are safety and rapid data collection (shorter missions) the key drivers?
Develop System and Staffing Plan	• Established UAS program with qualified staff, in-house UAS fleets, and support system forms a strong foundation. • Agency has an Incident Command System with consideration for multiple stakeholders.	• Procurement guidelines can be developed for additional services—staff availability was noted as a common challenge. • Consider exploring cellular network drones for emergency response missions. • An integrated organization can be established with external stakeholders, and suitable roles and responsibilities can be included in the SOP.	• Are adequate resources (team and system) available in-house to support the mission? • What are the performance requirements and specifications to be utilized for UAS-service providers?
Develop Flight Plan and Conduct Risk Assessment	VTrans SOP adequately covers the procedure for pre-flight planning (checklist) and risk assessment, although the FRA form is still under development and validation.	Agency can consider enhancing the existing guidelines with more inputs for SORA targeted towards emergency response.	• Are all the existing checklists evaluated for emergency response—risk assessment, instrument inspection (manufacturers)? • Are there additional considerations for external stakeholders in flight planning and risk assessment?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions For Decision to Support UAS Deployment
Obtain Permits and Waivers	VTrans manual includes guidance on flight restrictions requiring Part 107 compliance and prior approvals/waivers needed in flowing cases • Without a VO • In precipitation • Wind speed greater than 15 knots Allows provisions for emergency responders to act as VO with prior approval from UAS Program Manager.	• Guidance can be added to include considerations for waiver applications and methodical approaches to increase chances of success (covered in the Task 3 report). • LAANC considerations can be included in the manual for real-time authorization in controlled airspace (covered in the Task 3 report).	• Can the working relationship with FAA be leveraged to expedite the waiver approval process for emergencies? • Are all the required waivers/permits obtained within a suitable timeframe?
Obtain Approval and Perform Flight Operations	• The SOP contains detailed information on normal flight operations and highlights the authority for approval. • The SOP emphasizes the importance to transfer the data to the requestor.	Guidelines for data processing workflow can be expanded for typical video-streaming applications (Microsoft Streams) and image processing solution (Pix4D) proposed by the agency.	• Are all the prerequisites in place to request mission approval (flight plan, risk assessment results, checklists)? • Are on-site risk assessment results providing required inputs for RPIC for a final go-ahead decision? • Are flight controls and monitoring checklists available to use for emergency response and monitoring operations? • Are post-flight inspections and flight log reports complete?

3.2. IMPLEMENTATION PROCEDURE FOR PUBLIC OUTREACH AND ENGAGEMENT (RHODE ISLAND DOT)

Public outreach and engagement efforts constitute important components for transportation projects, and they play a key role in communicating vital information and harnessing public support for projects. Investments are often made in terms of technologies and dedicated public information teams to assist in this process. Timely dispensation of project information and continuous public engagement is essential to ensure successful project performance, especially in large and complex projects. The additional costs of outreach programs are far outweighed by the savings achieved from reduced road user delay costs (Choi et al., 2009). Technologies such as UAS have made significant strides in assisting public information efforts by enabling the acquisition of project images and videos for dissemination. Key benefits include increased effectiveness in accomplishing the objectives for public information, such as increased situational and contextual awareness of the public, increased likelihood of initial and continuous support for project success, and augmentation of successful chance with other mediums. Nonetheless, an agency needs to have a holistic implementation plan based on understanding the mission's objectives, assessing the existing capabilities and constraints, and engaging a suitable deployment strategy.

Step 1 – Define Mission Objectives

The first significant step in decision-making is clearly articulating the mission objectives and understanding the data collection scope necessary to assist the public outreach and engagement efforts. This may include collecting imagery and video data for reporting on project progress, communicating lane closures and detours, or visualization of existing or proposed conditions (in the form of 3D models). While the UAS technology is suitable to assist in some of these situations, it is essential to evaluate potential available alternative technologies and consider their potential constraints and drivers. State agencies rely on several mediums such as project websites, videos, social media, news reports, and public information meetings to convey the required information. Other technologies can collect the underlying visual data on job sites, such as static closed-circuit television (CCTV) and handheld cameras. Three-dimensional model data can be collected using mobile lidar or laser scanners. UAS can also augment the data collection efforts by providing high fidelity of existing conditions or proposed project progress, which helps convey valuable information about projects or other activities. It can also offer data in real-time (livestream) and to the required quality in necessary circumstances.

Step 2 – Develop System and Staffing Plan

Once a decision is made to deploy UAS based on an alignment of mission objectives, the second key step is to engage the necessary resources to support the flight mission from planning to data processing and closeout. This step includes the following:

Team Selection: Rhode Island DOT does not have an established UAS program. The agency is in the nascent stages of developing an in-house program with identified flight crew members and associated training requirements and guidelines. The existence of a UAS Working Group was noted during case studies with many staffers having UAS experience. Hence, the agency could rely on consultant services to deploy a UAS mission for collecting project data to support public outreach initiatives. In the future, it would be beneficial for the agency to consider developing an SOP with the roles and responsibilities of various personnel involved in the program. Developing qualification and training requirements for crucial flight crew members benefits the agency during the initial stages of the UAS program, especially while using service providers for the mission to support public outreach efforts.

System Selection: Collecting data for public outreach efforts can be done efficiently using UAS fitted with RGB cameras capable of producing high-resolution imageries and videos. Low-end UAS systems start with a 12 MP camera with 1080 HD video quality and scale up to a 20P camera with 4K video quality. A 20 MP RGB camera with 4K video capability at 60 frames per second would meet the resolution requirements for public engagement. Accuracy metrics such as GSD and horizontal and vertical accuracy may not be potential drivers for system selection unless a highly accurate 3D mesh model is desired as an outcome. Since Rhode Island DOT does not have an in-house UAS fleet, the agency could consider developing performance specifications for the end products delivered from consultant services. Some of the example aircraft platforms available that the agency could consider for procurement include Autel EVO II, DJI Phantom, Mavic, Matrice or, Inspire Series, and Intel Falcon 8+. Most of these platforms come with native software applications that support flight planning, mission control, and data processing.

Step 3 – Develop Flight Plan and Perform Risk Assessment

With mission objectives established and resources mobilized, the next critical step is to conduct a holistic risk assessment covering major flight planning activities in both the office and field environments. Rhode Island DOT could use the service providers' guidelines and ensure it includes considerations for the weather, crew experience, mission factors, and site-specific considerations (including obstacles, terrain, traffic, airspace). In general, it would be beneficial for the agency also to ensure a flight plan with a project map is included as part of the risk assessment.

Step 4 – Obtain Permits and Waivers

Step 4 includes ensuring compliance with Federal, State, and local regulations and evaluating a safety case to mitigate the operation's risk. It may be necessary to apply at FAA DroneZone for Part 107 waivers to collect data for public outreach efforts. Due to the nature of the operations, permission may be required to operate in controlled airspace. A LAANC procedure may be leveraged to obtain real-time authorization to operate under this situation, especially if the flight falls under pre-approved zones and altitude (as identified in FAA’s UAS Facility Maps). Procedures for these waivers are addressed in the Task 3 report. A good working relationship with the FAA is also recommended to expedite the waiver application and decision-making process.

Step 5 – Obtain Approval and Perform Flight Operations

With all the necessary permits and waivers in place and pre-flight planning procedures complete, the next step is the approval process. Considering Rhode Island DOT does not have an organized UAS program, an approval authority needs to be identified (either at a program- or project-level) to authorize the mission. It is important to identify and include the authority in the operations manual when the latter is developed.

Flight operations take place once approval is granted. This stage comprises three phases: site mobilization (pre-operations), flight operations, and data processing to obtain required deliverables. The three phases are described in detail in the Task 3 report, along with the process maps. An essential requirement is conducting an on-site hazard/risk assessment during the pre-operation stage before the RPIC gives the final go-ahead. Rhode Island DOT can consider developing its internal guidelines for the on-site risk assessment. For public outreach efforts, livestreaming of imagery or video data may be required in addition to the collection of images or videos. The agency could establish specifications to evaluate the quality of the end products to support public outreach efforts.

Step 6 – Assess Outcomes and Document Lessons Learned

With the UAS operations complete, the quality of the collected data is assessed against public outreach and engagement requirements. Metrics from UAS operations such as the resolution of imageries and videos and data transmission rate (for livestreamed data) provide useful information on gaps in technologies or support systems used during the process. Any technological, organizational, or policy guidelines noted over multiple missions can be leveraged to develop suitable refinements to the existing operations manual. Peer agencies can also play a vital role in sharing lessons learned and best practices to enhance operational efficiency. Some of the peer agencies to consider for public outreach include Virginia DOT, Ohio DOT, Utah DOT, Alabama DOT, and North Carolina DOT.

Table 3-4 summarizes the procedural requirements highlighted in the six steps presented in the section with the key questions to support decision-making for using UAS for public outreach and engagement missions.

Table 3-4. Implementation procedure for public outreach and engagement (Rhode Island DOT).

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Define Mission Objectives	Rhode Island DOT has informal guidelines from its UAS Working Group.	• Consider developing a detailed UAS Operations Manual (Section 2.0 of this report). • Incorporate recommendations for waiver applications (covered under Task 3) and use case indications.	• Are there alternative technologies to support public outreach and engagement? • Are safety issues, rapid data collection, bird's eye view of the project, or existing conditions the key driver?
Develop System and Staffing Plan	Agency has some staffers experienced with operating a UAS in compliance with FAA regulations.	• Procurement guidelines could be developed for consultant services—staff availability was noted as a common challenge. • Consider procurement of UAS systems and organizing staffing for key roles.	• Are adequate resources (team and system) available in-house to support the mission—quality checks in case of consultant services? • What are the performance requirements and specifications to be utilized for UAS-service providers?
Develop Flight Plan and Conduct Risk Assessment	Agency could develop an SOP that offers guidelines on the flight plan, safety management, and risk assessment based on literature and missions completed thus far.	Agency can consider enhancing the existing guidelines with more inputs for SORA.	• Are all the existing checklists evaluated for public outreach deployment—risk assessment, Instrument inspection (manufacturers)?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Obtain Permits and Waivers	Agency relies on FAA guidelines and state regulations—no specific guidelines exist thus far.	• Guidance can be added to include considerations for waiver applications and methodical approaches to increase chances of success (covered in the Task 3 report). • LAANC considerations can be included in the manual for real-time authorization in controlled airspace (covered in the Task 3 report).	• Can the working relationship with FAA be leveraged to expedite the waiver approval process for public outreach? • Are all the required waivers/permits obtained within a suitable timeframe?
Obtain Approval and Perform Flight Operations	Agency can include detailed guidelines in SOPs on normal flight operations, emergency plan, DARP, and other areas necessary for guiding a UAS mission; Section 2 of this report offers some insights.	Guidelines for data processing workflow can be expanded for typical video-streaming applications and image processing solution proposed by the agency.	• Are all the prerequisites in place to request mission approval (flight plan, risk assessment results, checklists)? • Are on-site risk assessment results providing required inputs for RPIC for a final go-ahead decision? • Are flight controls and a monitoring checklist available to use for public outreach and engagement programs? • Are post-flight inspections and flight log reports complete?

3.3. IMPLEMENTATION PROCEDURE FOR BRIDGE INSPECTION (MAINE DOT)

Bridge inspections play a vital role in ensuring public safety and confidence in bridge structural capacity and integrity. The process provides vital information to plan for maintenance and rehabilitation operations. Technologies such as UAS have made significant strides in assisting bridge inspectors and other key stakeholders gain access to a variety of data regarding conditions of bridge elements to collect asset inventory and effectively inform maintenance, repair, and rehabilitation schedules. Ohio State University and Ohio DOT have seen significant time saving using UAS over traditional methods. The primary benefits associated with the cost savings are from decreased field time, which in turn increases the safety of the inspectors and the general public (Mallela et al., 2018). Table 3-5 summarizes the savings for 15 different bridge inspections using UAS.

Table 3-5. Ohio DOT estimated savings from use of UAS for bridge inspections

	Personnel Time Saved (%)	Dollars Saved ($)
Average	10%	$3,900
Standard Deviation	3%	$2,700
Minimum	3%	$200
Maximum	15%	$10,500

Source: (Mallela et al., 2018)

As reported in Task 1, Oregon DOT also found cost benefits and reported an average savings of $10,200 per project in the following categories

- Savings in traffic control ($3,500).
- Savings in equipment rentals such as cranes ($2,800).
- Savings in personnel time for travel, lodging, data collection, and potential incidents ($3,900).

Many organizations are using UAS for significant benefits; however, for success, it is vital to understand the mission's objectives, assess the existing capabilities, and develop a suitable response strategy.

Step 1 – Define Mission Objectives

The first significant step in decision-making is clearly articulating the mission objectives and understanding the data collection scope necessary to assist the bridge inspection activities for various elements (substructure, superstructure, and deck elements). Bridge inspectors often rely on National Bridge Inventory Standards or relevant State guidelines that offer detailed procedural guidelines to support various inspections, including routine inspection, fracture-critical inspection, and underwater inspection, among others. State agencies need to report on these elements' conditions and prepare an inspection report that ultimately goes to the National Bridge Inventory database maintained by Federal Highway Administration. UAS technology is suitable in some of these situations, especially routine bridge inspection. Nonetheless, it is essential to evaluate potential alternative technologies available that can be deployed to achieve similar objectives.

Inspectors often use a variety of equipment for bridge inspection, including tools for cleaning the bridge, multiple measuring devices, remote cameras, and tablet personal computers or paper to record inspection data. Snooper trucks are often used across the country to collect the required data for various bridge elements. While often considered standard practice, this method has multiple challenges, especially regarding inspector safety, requirements for lane closures, and concerns regarding data granularity and accuracy.

UAS can support the mission individually or in combination with the other alternatives. UAS are beneficial because of their expanding ability to carry a variety of sensor payloads (including RGB cameras, lidar, infrared, and multi-spectral sensors). They also give inspection teams the ability to live stream data remotely. Many of these features make it a cost-effective and safe tool to collect data to identify various defects such as cracks and concrete delamination. Table 3-6 compares alternative technologies based on several performance metrics often considered for selection at this level.

Table 3-6. Alternative technologies comparison for bridge inspection.

Technology	Quality of Data	Type of Inspection	Cost	Safety of Data Collection	Duration
Snooper Trucks	Low-moderate	Routine and fracture-critical	High	Moderate	High
UAS Inspection	Moderate-high	Routine inspection	Low-moderate	High	Low

Step 2 – Develop System and Staffing Plan

Once mission objectives are aligned and the decision to deploy UAS is made, the second key step is to engage the necessary resources to support the flight mission from planning to data processing and closeout. This step includes the following:

Team Selection: Maine DOT has an established UAS program under its Bureau of Engineering and Construction that includes an experienced team with a Program Coordinator (Chief Engineer), FAA-certified remote pilots, and VOs. The agency has developed a UAS SOP and a policy that provides guidance on the flight crew's qualifications and experience required for any UAS mission. The UAS policy also includes a point of contact and procedures to request procurement of consultant services.

System Selection: Bridge inspection operations normally require UAS platforms that meet stringent minimum GSD requirements (minimum GSD~ 1 cm) with reasonably good accuracy (HA ~ 2.5cm, VA ~ 5cm). These specifications enable the collection of detailed data, especially regarding potential bridge defects. Maine DOT also has internal guidelines for element level inspections for bridges that require the determination of condition states of each critical element. This specification also plays a vital role in determining sensor payloads. Maine DOT currently has two DJI Phantom 4 multirotor drones based on specifications and software useful for bridge response. The following DJI-related software packages are used to support UAS operations and data processing:

- DroneLogBook – mission planning, compliance and maintenance reporting, and custom forms.
- DJI Go 4 App – flight operations and data collection/sharing.
- DJI Assistant 2 software – manage firmware, calibrate sensors, view flight data, and simulate flights.
- Pix4D and other standalone image and video editing software.

The agency could consider testing and expanding its fleet to include UAVs that could work in constrained-space environments. It could also include internal safety protocols that trigger an immediate warning message in the control application in the event of an imminent GPS-signal loss and enable switching to manual mode to enable direct control by RPIC. These are commonly reported as inhibitors in widespread UAS deployment for bridge inspection. A platform with a sensor with zoom capability could enable flying at a safe distance from obstacles while still maintaining sufficient detail.

In general, the agency is suitably positioned to perform most of the necessary work in-house unless the mission requires specific skillsets or crew members are not available. It would be beneficial to develop and validate policy guidelines for the procurement of UAS-services if the requirement arises. The agency's UAS policy provides some guidance on UAS-related equipment and services procurement in this regard.

Step 3 – Develop Flight Plan and Perform Risk Assessment

With mission objectives established and resources mobilized, the next critical step is to conduct a holistic risk assessment that covers major flight planning activities in both office and field environments. Maine DOT's SOP or policy document does not contain a dedicated pre-flight or risk assessment checklist but offers general guidance on inspections, weather, and planning. It also necessitates mission compliance with Part 107 guidelines. It would be beneficial for the agency to include a flight plan as part of the risk assessment process with a detailed project map and description of the project. For the bridge inspection use case, it might be relevant to include warning considerations or potential solutions in the SOPs. This would include safety concerns arising from metallic objects in the bridge that can affect the drone's stability and address operations in strong wind currents, especially beneath the bridge deck. Lane closures and traffic managing strategies may also be needed to ensure mobility, especially on highways with high traffic volumes. Some of these guidelines can be found in the Task 3 report.

Step 4 – Obtain Permits and Waivers

Step 4 includes ensuring compliance with Federal, State, and local regulations and evaluating a safety case to mitigate risk associated with bridge inspections. Due to the nature of the operations, deploying UAS for bridge inspection may require waivers for operating BVLOS (107.31) and permission to operate in controlled airspace. A LAANC procedure may be leveraged to obtain real-time authorization to operate under these situations, especially if the flight falls under pre-approved zones and altitude (as identified in FAA's UAS Facility Maps). Procedures for these waivers are addressed in the Task 3 report. A good working relationship with the FAA is also beneficial to support the waiver application process.

Step 5 – Obtain Approval and Perform Flight Operations

With all the necessary permits and waivers in place and pre-flight planning procedures complete, the next step is to obtain mission approval. Maine DOT has identified the personnel (UAS Program Coordinator) who authorizes the mission. Once approved, flight operations can occur. This stage comprises three phases: site mobilization (pre-operations), flight operations, and data processing to obtain required deliverables. The three phases are described in detail in the Task 3 report and include process maps. During the pre-operation stage, a key requirement is conducting an on-site hazard/risk assessment before the RPIC gives the final go-ahead. Maine DOT's operations manual does not contain explicit checklists for FRA. The agency could consider including checklists for risk assessment, routine procedures, and an in-flight emergency plan. Transitioning to desktop or cloud-based image processing solutions could also facilitate a holistic workflow to generate the required deliverables and assess or quantify the extent of the damages (e.g., DSMs 3D point clouds, orthomosaics).

Step 6 – Assess Outcomes and Document Lessons Learned

With the UAS operations complete, the quality of the data is assessed against the bridge inspection requirements. Metrics from the UAS operation, such as accuracy, point density, GSD, and resolution, provide useful information on gaps in technologies or support systems used during the process. Any changes to the technological, organizational, or policy guidelines noted over multiple missions can be leveraged to develop suitable refinements to the existing operations manual. Peer agencies can also play a vital role in sharing lessons learned and best practices to enhance operational efficiency. Some of the peer agencies to consider for bridge inspection include MassDOT (Ni & Plotnikov, 2019), Louisiana DOT (Darby & Gopu, 2018), and Minnesota DOT (Lovelace, 2018).

Table 3-7 summarizes the procedural requirements highlighted in the six steps presented in the section with the key questions to support decision-making for using UAS for bridge inspection missions.

Table 3-7. Implementation procedure summary for bridge inspection.

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key questions for Decision to Support UAS Deployment
Define Mission Objectives	• Maine DOT has a UAS SOP and policy that lays out general guidelines for mission objectives. • The agency also has element-level specifications for bridge inspection.	Incorporate recommendations for waiver applications (covered under Task 3) and use case indications in SOP.	• Is the main objective to support routine bridge inspection? • Are there alternative technologies to support bridge inspection? • Are the following issues anticipated during UAS operations in the field—wind shear, magnetic interference (metallic elements), GPS loss?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key questions for Decision to Support UAS Deployment
Develop System and Staffing Plan	Established UAS program with qualified staff, in-house UAS fleets, and support system forms a strong foundation.	• Procurement guidelines could be developed for consultant services—staff availability was noted as a common challenge. • Consider procurement of UAS with autonomous flight control to provide alerts on imminent GPS loss or use UAS that can operate in GPS denied environments.	• Are adequate resources (team and system) available in-house to support the mission—quality checks in case of consultant services? • What are the performance requirements and specifications to be utilized for UAS-service providers?
Develop Flight Plan and Conduct Risk Assessment	Maine DOT's SOP includes considerations for pre-flight planning, inspections, weather, and post-flight log reports. Detailed checklists are yet to be developed and validated.	• The agency can include checklists in the SOP for pre-flight planning, risk assessment, instrument inspection. • Agency can consider enhancing the existing guidelines with more inputs for SORA.	• Are all the existing checklists evaluated for UAS deployment for bridge inspection—risk assessment, instrument inspection (manufacturers)?
Obtain Permits and Waivers	Agency relies on FAA guidelines and state regulations in their SOP and policy manuals–no specific guidelines exist thus far.	• Guidance can be added to include considerations for waiver applications and methodical approaches to increase chances of success (covered in the Task 3 report). • LAANC considerations can be included in the manual for real-time authorization in controlled airspace (covered in the Task 3 report).	• Can the working relationship with FAA be leveraged to expedite the waiver approval process for bridge inspection? • Are all the required waivers/permits obtained within a suitable timeframe? • Can the agency bundle inspection sites into one waiver application for approval (e.g., Minnesota DOT's approach described in the Task 3 report)?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key questions for Decision to Support UAS Deployment
Obtain Approval and Perform Flight Operations	Agency can consider expanding its guidelines in SOPs on normal flight operations, emergency plan, DARP, and other areas necessary for guiding a UAS mission; Section 2 of this report offers some insights.	Guidelines for data processing workflow can be expanded to include image processing solutions generally applicable for bridge inspection.	• Are all the prerequisites in place to request mission approval (flight plan, risk assessment results, checklists)? • Are on-site risk assessment results providing required inputs for RPIC for a final go-ahead decision? • Are flight controls and monitoring checklists available to use for bridge inspection operations? • Are post-flight inspections and flight log reports complete?

3.4. IMPLEMENTATION PROCEDURE FOR SURVEYING AND MAPPING (NEW HAMPSHIRE DOT)

The surveying and mapping industry has been at the forefront of adopting UAS technology because of its inherent similarity to conventional aerial mapping. The industry created a new aerial mapping method with low-cost UAS platforms equipped with high-resolution imaging sensors and lidar payloads. The use of UAS has created a substantial return on investment for DOTs for specific applications.

- Utah DOT estimates that using UAS can reduce surveying time by as much as 50 percent while improving safety (FHWA, 2020).
- Montana DOT reported that the cost of the UAS systems and hardware was just over $10,000, while there were savings in the man-hours spent in collecting data safely and at scale (Beal, 2019).

While the technique used in conventional aerial photogrammetry and UAS aerial photogrammetry is fundamentally similar in many ways, the application differs largely due to regulations and operating procedures. It is also worth noting that using a variety of tools and incorporating their strengths into one data set can provide the most significant benefit (Mallela et al., 2018).

Step 1 – Define Mission Objectives

Broadly speaking, there are two methods of UAS aerial mapping. UAS photogrammetry is a simple alternative to conventional manned aerial photogrammetry suitable for small areas. The other method uses a UAS lidar sensor capable of penetrating foliage and producing a bare earth surface model. Both UAS mapping methods are equivalent to large fixed aircraft aerial mapping methods, but the advantage lies in mobilization and accessibility. It is common to consider UAS aerial mapping without careful examination of the project scope; some cases are more suitable for manned fixed-wing aircraft aerial mapping methods than UAS. The scope requirements for the various methods are summarized below.

- **Manned Aerial Photogrammetry** is a conventional method of aerial mapping using aerial photographs to compute ground elevation. This method is appropriate for large areas such as long highway corridors or densely populated urban areas.
- **Manned Lidar Mapping** uses an active laser beam to measure the distance from the sensor to the target and computes the elevation of the ground. This method has an advantage in dense tree canopy and foliage areas where bare earth surface needs to be mapped. Often, it can be carried out simultaneously as the photogrammetry mission, but the sensor and processing time can be costly.
- **UAS Aerial Photogrammetry** uses a technique similar to the technique used in manned aerial photogrammetry. Manned aerial photogrammetry uses a stereo scoping technique. The fundamentals of this method are translated directly to a computerized process called structure from motion; sometimes it is called multi-view stereo. UAS aerial photogrammetry is suitable for small to medium-sized areas such as smaller roadway corridors, commercial construction sites, and road intersection projects. Typically, corridor lengths of 5 miles or less are practical for UAS operations. UAS have a significant advantage in mobilization and processing time and is cost-efficient compared to manned aerial photogrammetry. Higher ground sampling can typically be achieved, and UAS avoid limitations with clouds obscuring the ground.
- **UAS Aerial Lidar Mapping** has advantages in areas with shadows, highly reflective surfaces, or heavy foliage where high point cloud density and canopy penetration is required for the bare earth surface model.

Each UAS mapping method can support the mission individually or in combination with the other surveying methods. Ground-based surveying can provide isolated quality control parameters to the aerial data. These methods require ground control targets to achieve the accuracy set by the American Society of Photogrammetry and Remote Sensing and the state regulators illustrated in Table 3-8.

Table 3-8. Technology comparison for surveying and mapping.

Technology	Quality of Data	Cost	Area Coverage	Duration
Manned Aerial Photogrammetry	Moderate	Moderate	Very high	Longer missions
Manned Aerial Lidar	Moderate-high	Moderate-high	Very high	Longer missions
UAS Aerial Photogrammetry	Low-moderate	Low	Medium	Shorter-medium missions
UAS Aerial Lidar	Moderate-high	Low-moderate	Small	Short missions

Step 2 – Develop System and Staffing Plan

Once the decision to deploy UAS is made based on an evaluation of the mission objectives and comparing alternative approaches, the next step is to develop a systems and staffing plan.

Team Selection: UAS mapping missions usually require a two-person flight crew. The primary pilot is responsible for the aircraft's airworthiness and flight operation. A VO is responsible for reporting any changes during the flight and risks that may arise unexpectedly. Three or more VOs may be required in urban areas or high-risk environments such as roadways.

System Selection: Surveying and mapping UAS operations typically fly higher altitudes than other applications such as bridge inspection. Multi-rotor platforms have gained popularity among surveyors when mapping a small area. Multi-rotor UAS are equipped with a 3-axis gimbal that stabilizes the camera. Fixed-wing UAS can fly longer and cover a larger area; however, manned aerial mapping is still preferred for large area aerial mapping.

Step 3 – Develop Flight Plan and Perform Risk Assessment

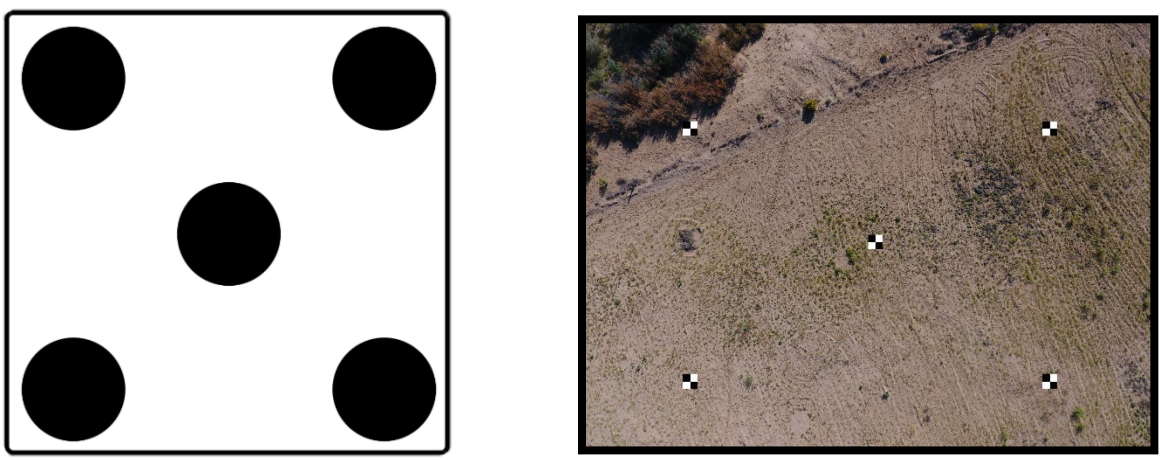
The flight planning stage includes several key considerations for a successful mission. The final accuracy of the result is solely dependent on the flight plan and ground-truthing. It is crucial for a pilot in command to review these items to achieve the desired accuracy.

Area Calculation: The area of interest and aerial survey limit is calculated using mapping software such as Google Earth. Surveying and mapping applications often cover large areas, and the total mapping area is essential information necessary to compute battery requirements and total flight time.

Flight Path Design: Flight path design is the process to plan the aircraft flight pattern to achieve the desired accuracy and optimal results. In sUAS photogrammetry, 70 to 80 percent front overlap is recommended with no more than 10,000 pixels between two GCPs. Therefore, it is important to design a flight path that allows ideal GCP placement within the specific site condition. For example, a long narrow roadway corridor flight path should be flown parallel to the centerline of the road with GCPs placed in every 10,000-pixel interval. Also, flight path design should consider ground feature type to optimize photogrammetric pattern searching and matching algorithms and avoid highly reflective features like water bodies or repeating patterns such as gravel and sand.

Ground Control Points: GCP placement plays a crucial role in UAS photogrammetry and can directly affect the accuracy of the result. The placement of the points should be aligned like the five sides of a die across the site. The GCPs should not be too close to the edge of the flight area where there is minimal overlap of the images, as illustrated in Figure 3-1. Poorly designed GCP placement can result in severe distortions in elevation and lead to failure in the aero-triangulation process. The type of GCP is governed by the resolution of the imaging sensor and the altitude of the flight. It can be as small as a painted triangle on the pavement or as large as a 3-foot x 3-foot reflective tape placed on the ground in a chevron shape. Recommended ground targets are at least five times bigger than the desired ground sampling distance. GCPs should have high contrast against the background to be easily seen in the imagery. They can be created from paint, aerial target tape, or other simple items such as bucket lids, foam core, or other suitable material, depending on the project's needs. Other solutions are available such as Propeller Aeropoints, which can provide a complete GCP solution without additional surveying.

Figure 3-1. Ground control placement example. Left: GCP arranged as the five side of a die. Right: GCP location relative to area to be flown.



Step 4 – Obtain Permits and Waivers

Step 4 includes ensuring compliance with Federal, State, and local regulations and evaluating a safety case to mitigate risk associated with the operation. It may be necessary to apply at FAA DroneZone for Part 107 waivers to collect data for surveying and mapping. Additionally, it may be beneficial for larger areas to apply for a BVLOS (107.31) waiver. Some operations may require permission to operate in controlled airspace, in which case, a LAANC procedure may be leveraged to obtain real-time authorization to operate under this situation, especially if the flight falls under pre-approved zones and altitude (as identified in FAA's UAS Facility Maps). Procedures for these waivers are addressed in the Task 3 report. A good working relationship with the FAA is recommended to expedite the waiver application and decision-making process.

Step 5 – Obtain Approval and Perform Flight Operations

Once regulatory permits and waivers are in place, New Hampshire DOT-designated personnel should assess the flight operation and authorize the mission. Once the mission is authorized, the flight crew can proceed to conduct the flight as planned.

Step 6 – Assess Outcomes and Document Lessons Learned

The result should be analyzed by several different methods. The post-processing photogrammetry software or the lidar report must be cross-referenced and checked by ground survey observations. Additional findings and errors should be recorded and compiled to the final report.

Table 3-9 summarizes the procedural requirements highlighted in the six steps presented in the section with the key questions to support decision-making for using UAS for surveying and mapping missions.

Table 3-9. Implementation procedure for surveying and mapping.

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Define Mission Objectives	NHDOT survey manual NHDOT Directive notes sUAS	Guidelines can be strengthened for waiver applications (covered under Task 3) and use case indications.	• What are the restrictions with flying over private property? • What is the achievable accuracy, and does it meet the minimum standard?
Develop System and Staffing Plan	Established UAS program with qualified staff, in-house UAS fleets, and support system forms a strong foundation.	Directive notes can be developed into an operational guideline.	• Are adequate resources available in-house to support the mission? • What are the performance requirements and specifications to be used for UAS-service providers?
Develop Flight Plan and Conduct Risk Assessment	NHDOT directional notes provide general guideline.	Develop internal flight operation GIS software for all pilots flying in NH to register their flight plan.	• Are all the existing checklists evaluated for emergency response—risk assessment, instrument inspection (manufacturers)? • Are there additional considerations for external stakeholders in flight planning and risk assessment?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Obtain Permits and Waivers	Current FAA Part 107 guidelines	• Guidance can be added to include considerations for waiver applications, methodical approaches and to increase chances of success (covered in the Task 3 report). • LAANC considerations can be included in the manual for real-time authorization in controlled airspace (covered in the Task 3 report).	• Can the working relationship with FAA be leveraged to expedite the waiver approval process for surveying? • Are all the required waivers/permits obtained within a suitable timeframe?
Obtain Approval and Perform Flight Operations	The SOP contains detailed information on normal flight operations and highlights the authority for approval.	Guidelines for data processing workflow and the accuracy assessment can be expanded for image processing solutions proposed by the agency.	• Are all the prerequisites in place? • Are flight controls and monitoring checklists available to use? • Are post-flight inspections and flight log reports complete?

3.5. IMPLEMENTATION PROCEDURE FOR CONSTRUCTION INSPECTION (CONNECTICUT DOT)

UAS have been widely adopted in bridge inspection and the surveying and mapping industry; now, it has begun to be adopted in construction inspection. UAS provides valuable information for the safety and integrity of the construction sites that improve the quality and the safety of the workers and the public. The key is to successful data collection is to follow the guidelines as illustrated in Figure 3-2.

Figure 3-2. Flowchart. General guidance for effective use of geospatial tools in highway construction projects.

Source: (Mallela et al., 2018)

While UAS is still at an early stage of adoption, it is not an overstatement to assume that every construction company owns and operates UAS in various ways. Contractors have found numerous benefits from using UAS documented by (Mallela et al., 2018), which includes:

- Improved safety benefits, although this is difficult to quantify. For example, there are fewer minor injuries (especially for people measuring stockpiles, climbing slopes).
- Increased coverage and accuracy with aerial surveys of material piles.
- Significant time savings for survey data collection and data processing and calculations.
- Videos and images of places not easily accessed before (e.g., steep slopes).

The key components for success while using UAS for construction inspection are described in further detail below.

Step 1 – Define Mission Objectives

In most circumstances, UAS is used to collect information to make crucial decisions in a continuously changing construction site. Similar to bridge inspection, the nature of construction inspection inevitably needs to be performed on the ground. This requirement limits UAS inspection because UAS can only provide visual information. Therefore, UAS inspection is used in conjunction with a physical inspection to assist inspectors and engineers.

Table 3-10 summarizes on-ground versus UAS inspections and compares their cost, safety, and time for collection.

Table 3-10. Alternative technologies comparison for construction inspection.

Technology	Quality of Data	Type of Inspection	Cost	Safety of Data Collection	Duration
On-ground Inspection	Moderate-high	Physical inspection	High	Moderate	High
UAS Inspection	Low-moderate	Visual inspection	Low-moderate	High	Low

Step 2 – Develop System and Staffing Plan

Using UAS for construction inspection is often a routine process used to detect and analyze changes, calculate quantities, and provide sufficient information for visual checks. It is strongly recommended that the system and staff operating the UAS are familiar with the site and responsible for the repeatability of the mission.

Team Selection: Selecting a team is crucial to the success of the data collection, and the team should be selected based on the goals for the collection. Connecticut DOT has pilot training requirements in its UAS SOP. The procedures allow a VO to be anyone on the construction site for the duration of the flight mission. VOs are imperative to a safe operation in complex environments with many obstacles, such as a construction site. The VO should be appropriately trained to understand the flight plan, aircraft capabilities, risk mitigation plan, Part 107 rules, emergency procedures, and how to look for obstacles and relay pertinent information to the RPIC.

System Selection: Construction inspection is generally focused on results in a fast-paced environment. Contractors use multi-rotor and fixed-wing UAS platforms with a variety of sensors depending on their data goals. Commercially available, multi-rotors can cover up to 50–200 acres using multiple batteries. A 3-axis gimbal system and a high-resolution camera are readily built into most UAS on the market. For larger areas, fixed-wing aircraft are often used to complete the data collection due to their extended flight times. The visual inspection of the aerial photograph can provide valuable information; however, full 3D modeling and orthomosaic compilation can bring the most significant benefit to construction inspection. The workflow and the system should follow surveying and mapping criteria to provide the most accurate data.

Step 3 – Develop Flight Plan and Perform Risk Assessment

UAS flight plans differ based on the type of inspection flight. Visual inspection can be performed by monitoring live images on a tablet or controller, broadcasting a livestream of the flight, using special goggles that display live imagery to the wearer, or automated flights. For automated flights in changing terrain, it is imperative to have software that allows the aircraft to fly at a relative reference altitude above the terrain instead of a static fixed height above the home point. This allows for a consistent ground sampling distance across the entire site and a more accurate deliverable. For a routine inspection flight, the following criteria should be considered.

Flight Frequency: To monitor the progress of construction, the flight schedule should be set regularly. Flight frequency criteria are based on the type of construction, the purpose of the inspection, and the construction phase's inspection requirements.

Flight Repeatability: In construction inspection, flight repeatability is crucial to monitor any construction changes. To achieve a high level of repeatability, the pilot can use pre-configured flight plans and execute the same flight pattern stored in the software every time.

Data Accuracy: When a flight is repeated in the same area at a set frequency, permanent GCPs are strongly recommended to control the accuracy of the data. In an active construction site, the locations of these control points should be carefully selected where they will not be disturbed by the construction activities. Once placed and used for control, the same control point should be used repeatedly.

Step 4 – Obtain Permits and Waivers

Step 4 includes ensuring compliance with Federal, State, and local regulations and evaluating a safety case to mitigate risk associated with construction inspection. Due to the nature of the operations, deploying UAS for construction inspection may require waivers for operating BVLOS (107.31) and permission to operate in controlled airspace. A LAANC authorization may be leveraged to obtain real-time authorization to operate under this situation, especially if the flight falls under pre-approved zones and altitude (as identified in FAA's UAS Facility Maps). Procedures for these waivers are addressed in the Task 3 report. A good working relationship with the FAA is also beneficial to support the waiver application process.

Step 5 – Obtain Approval and Perform Flight Operations

Construction sites are strictly controlled on the ground and in the air for safety reasons. The construction site safety manager should review and approve the operation and safety assessment. Routine flights should be conducted during the day when few shadows are present for repeatability and to improve the quality of the data.

Step 6 – Assess Outcomes and Document Lessons Learned

Documenting and cataloging images and flight data can become challenging due to the size of the data set. Although each image and video are time marked in their metadata, the pilot should record the data with an organized and standardized naming convention.

Table 3-11 summarizes the procedural requirements highlighted in the six steps presented in the section with the key questions to support decision-making for using UAS for construction inspection.

Table 3-11. Implementation procedure for construction inspection.

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Define Mission Objectives	Agency has a UAS SOP and policy that lays out general guidelines for mission objectives.	Incorporate recommendations for waiver applications (covered under Task 3) and use case indications in SOP.	• Routine inspection or structure inspection? • Image or video or mapping?
Develop System and Staffing Plan	Established UAS program with qualified staff, in-house UAS fleets, and support system form a strong foundation.	• Develop UAS pilot training for construction inspection. • Fully automate sUAS system for routine inspection flights.	• Are adequate resources (team and system) available in-house to support the mission—quality checks in case of consultant services? • What are the performance requirements and specifications to be utilized for UAS-service providers?
Develop Flight Plan and Conduct Risk Assessment	Agency SOP includes considerations for pre-flight planning, inspections, weather, and post-flight log reports.	The agency can include checklists in SOP for pre-flight planning, risk assessment, and instrument inspection.	• Are all the existing checklists evaluated for UAS deployment for construction inspection?
Obtain Permits and Waivers	Agency relies on FAA guidelines and state regulations in its SOP and policy manuals—no specific guidelines exist thus far.	• Guidance can be added to include considerations for waiver applications, methodical approaches and to increase chances of success (covered in the Task 3 report) • LAANC considerations can be included in the manual for real-time authorization in controlled airspace (covered in the Task 3 report).	• Can the working relationship with FAA be leveraged to expedite the waiver approval process for construction inspection? • Are all the required waivers/permits obtained within a suitable timeframe?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Obtain approval and perform flight operations	Agency can consider expanding its guidelines in SOP on normal flight operations, emergency plan, DARP, and other areas necessary for guiding a UAS mission; Section 2 of this report offers some insights.	Guidelines for data processing workflow can be expanded to include image processing solutions generally applicable for construction inspection.	• Are all the prerequisites in place to request mission approval (flight plan, risk assessment results, checklists)? • Are on-site risk assessment results providing required inputs for RPIC for a final go-ahead decision? • Is monitoring checklist available to use for construction inspection operations? • Are post-flight inspections and flight log reports complete?

3.6. IMPLEMENTATION PROCEDURE FOR TRAFFIC ANALYSIS (MassDOT)

The aerial accessibility provided by UAS and the availability of scalable and efficient computer vision algorithms create an excellent potential for using UAS for traffic analysis applications. UAS equipped with a high-resolution camera flying at a high altitude provides an aerial view of live traffic data. Recent advancements in computer vision can detect and analyze the speed, count, flow, and sometimes make decisions independently. Although there are limitations (e.g., altitude ceiling and short battery life), the prospect of UAS application in traffic monitoring is tremendous. Using UAS for traffic analysis could see savings of $75 million nationally (Carroll & Rathbone, 2002). The use of tethered UAS can also provide a solution when longer duration flights are necessary. Using UAS where fixed cameras are not available or practical can also increase the benefits. However, UAS will not entirely replace fixed cameras, detection loops, or other technological advances that allow for continuous operations. Some of the same technological breakthroughs, such as artificial intelligence and machine learning, can be used regardless of the platform collecting the data. The components for success for using UAS for traffic analysis are described in further detail below.

Step 1 – Define Mission Objectives

The advantage of UAS in traffic analysis is the wide coverage from the air and the ability to move across the site quickly. The area UAS can cover is only limited by the altitude ceiling set by the FAA Part 107 rule. Ground-based traffic counts are still preferred because of their cost efficiency and the immaturity of UAS aerial traffic monitoring, but the benefits of UAS traffic analysis far exceed the manned traffic analysis. The alternative method to UAS traffic analysis is

CCTV camera traffic analysis. The core component of the UAS traffic analysis is computer vision technology, which can also be applied to any CCTV footage that observes traffic at all times Table 3-12.

Table 3-12. Alternative technologies comparison for traffic analysis.

Technology	Quality of Data	Type of Analysis	Cost	Safety of Data Collection	Duration
UAS Traffic Analysis	Moderate-high	Aerial video analysis	High	Moderate risk	Short
CCTV Traffic Analysis	Moderate-high	Video analysis	Medium	Low risk	Long
On-ground Traffic Analysis	Low-moderate	Manual analysis	Low-moderate	Moderate risk	Medium

Step 2 – Develop System and Staffing Plan

The system and staffing plan should be created based on the mission objectives and will include selecting the airframe, sensor, software, and staff that best meet the collection, processing, and data management goals.

Team Selection: MassDOT has been engaged in UAS integration across aeronautics, rail and transit, highways, and the emergency management sectors. MassDOT developed a pilot program to integrate UAS technology into bridge and rail inspections that guide flight procedures and provide checklists prior to conducting a UAS flight. For successful traffic management using UAS, it is important to include someone familiar with traffic analysis on the team in addition to the RPIC and VOs. A data expert with knowledge of artificial intelligence and machine learning can also be a beneficial team member to increase productivity and data quality.

System Selection: Traffic analysis requires UAS that can fly for the desired length of the traffic analysis. If the traffic analysis time block is less than 30 minutes, multiple UAS batteries can be used to capture data during each block of time. However, if continuous traffic monitoring is needed, a tethered system is required. Some systems can be modified to a customized tethered system, but tethered UAS vendors also provide redundant safety nets to ensure safe operation. Currently, there are limited computer vision analysis vendors for traffic monitoring and analysis. Europe has been at the forefront in developing complex algorithms for video analysis in traffic monitoring, and European-based companies provide the most innovative traffic monitoring software.

Step 3 – Develop Flight Plan and Perform Risk Assessment

As previously mentioned, the current FAA Part 107 rule limits UAS to fly higher than 400 feet above the ground without a COA. At an altitude of 400 feet, UAS cameras equipped with a full-frame imaging sensor can only capture about a quarter section of the major highway intersection. To overcome this narrow view angle, a pilot can tilt the camera angle up to 45 degrees from straight down or use another sensor or lens with a wider field of view. A majority of battery-powered UAS are limited to 25–45-minute flight times. Tethered UAS can overcome this limitation, but this technology comes with a higher cost and additional operational procedures.

Flight Altitude: When flying for monitoring traffic, the correct camera with a focal length sufficient to capture the area should be used. In situations where this is not possible, multiple drones can be used to capture the area to provide sufficient overlap to capture the entire area of interest. However, this approach requires complex field operations and creates exposure to many sources of error. If a permanent structure such as a transmission tower or a telecommunication tower is available, a pilot can use these structures to increase flight altitude. Care should be taken to not fly more than 400 ft laterally from them to prevent violation of Part 107 rules. When using high-resolution full-frame cameras with a limited field of view, the ideal flight altitude should be between 800 to 1,200 feet, which requires an FAA COA to fly at these altitudes.

Vantage Point and Camera Angle: To overcome the altitude limitation, sUAS pilots can adjust the camera angle to capture more vehicle flow in a frame. Although a straight-down camera view provides ideal properties to calculate velocity, acceleration, and flow patterns, many available traffic flow video analysis tools can detect and track vehicles in an angled camera view. In most situations where an automated traffic flow analysis tool is used, the camera angle should not exceed 45 degrees from the straight down nadir view.

Flight Time and Battery: Currently available off-the-shelf sUAS platforms are mostly limited to 25–45 minutes of flight time. It is a common requirement to monitor traffic for blocks of time that span from an hour to four hours. The pilot can use multiple sUAS aircraft and switch them for continuous monitoring, but this approach can create inconsistencies and post-processing problems. Ultimately, it is ideal to have one aircraft stationary for desirable lengths of time. Tethered sUAS can be beneficial for extended duration flights when required. There are tethered sUAS vendors within the USA, and some include an integrated system with the camera, eliminating the need for a battery for the sensor.

Step 4 – Obtain Permits and Waivers

Step 4 includes ensuring compliance with Federal, State, and local regulations and evaluate a safety case to mitigate risk associated with traffic analysis. Due to the nature of the operations, deploying UAS may require waivers for operating BVLOS (107.31) and permission to operate in controlled airspace. A LAANC authorization may be leveraged to obtain real-time authorization to operate under this situation, especially if the flight falls under pre-approved zones and altitude (as identified in FAA's UAS Facility Maps). Procedures for these waivers are addressed in the Task 3 report. A good working relationship with the FAA is also beneficial to support the waiver application process. Tethered UAS are regulated under 14 CFR Part 107. There was some confusion about the oversight for tethered UAS (i.e., whether it fell under Part 101 or Part 107 rules). The FAA clarified its stance that UAS, even when tethered, must comply with Part 107 or obtain a COA.

Step 5 – Obtain Approval and Perform Flight Operations

Flying over the high traffic volume is strictly prohibited by the FAA Part 107 rule. The pilot should designate a safe launch location to comply with the regulation. If the area of interest does not fall within controlled airspace, coordination with appropriate authorities who may be affected is beneficial to ensure a safe operation. If the operation is within controlled airspace, a LAANC or a COA would be needed to operate. Tethering can create additional obstacles to prevent conflicts from being in the air for longer durations. It can be beneficial to issue a Notice to Airman to inform air traffic of the operation when flying for longer durations.

Step 6 – Assess Outcomes and Document Lessons Learned

Raw data from the UAS can have large file sizes and should be converted and stored systematically. Depending on the length and the system used, an optimum cataloging and documentation method should be studied.

Table 3-13 summarizes the procedural requirements highlighted in the six steps presented in the section with the key questions to support decision-making for using UAS for traffic analysis.

Table 3-13. Implementation procedure summary for traffic analysis.

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Define Mission Objectives	MassDOT has pilot program integration documents and an interim drone policy.	Incorporate recommendations for waiver applications (covered under Task 3) and use case indications in SOP.	• Pilot program for traffic analysis? • Current UAS traffic analysis can only focus on a small area?
Develop System and Staffing Plan	MassDOT has an established UAS program with qualified staff, in-house UAS fleets, and support system form a strong foundation.	• Develop UAS pilot training for traffic analysis. • Fully automate sUAS system for repetitive missions.	• Are adequate resources (team and system) available in-house to support the mission? • What are the data output and accuracy of the computer analysis tools?

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Develop Flight Plan and Conduct Risk Assessment	MassDOT pilot program includes considerations for pre-flight planning, inspections, weather, and post-flight log reports.	The agency can include checklists in SOP for pre-flight planning, risk assessment, and instrument inspection.	• Are all the existing checklists evaluated for UAS deployment for traffic analysis?
Obtain Permits and Waivers	Agency does not have guidelines to pursue advanced waivers such as airspace altitude waiver.	• Guidance can be added to include considerations for waiver applications and methodical approaches to increase chances of success (covered in the Task 3 report). • LAANC considerations can be included in the manual for real-time authorization in controlled airspace (covered in the Task 3 report).	• Can the working relationship with FAA be leveraged to expedite the waiver approval process for traffic analysis? • Can the agency apply for an advanced waiver to increase the altitude ceiling above 400 feet?
Obtain Approval and Perform Flight Operations	Agency can consider expanding its guidelines in an SOP on normal flight operations, emergency plans, DARP, and other areas necessary for guiding a UAS mission; Section 2 of this report offers some insights.	Create guidelines for data output and integrate UAS traffic analysis into the current traffic analysis procedure.	• Are all the prerequisites in place to request mission approval (flight plan, risk assessment results, checklists)?

4.0 SUMMARY AND CONCLUSION

The availability of reliable and proven UAS platforms and support systems provide significant opportunities for transportation agencies to integrate these tools to support digital data collection for various applications. Establishing a holistic UAS program and developing the necessary guidelines are the primary steps to ensuring successful UAS missions and sustaining and scaling the program in the future to benefit the agency and its various departments. This report provides an overview of the components that constitute an SOP and reviews the adequacy of the existing guidelines of New England State DOTs toward achieving the requirements for those topics. Based on the latest versions of the SOPs and policies available with the research team, it was found that:

- Most of the New England State DOTs generally refer to the existing FAA Part 107 guidelines in their operation manuals or policy directives as a minimal requirement for deploying UAS missions.
- All the agencies have an organized structure for a UAS program with at least the program in-charge identified and enlisted in their manuals.
- Topics such as post-flight data processing, DARP, guidelines for obtaining waivers, and use-case indications need to be adequately addressed.

Table 4-1 reconciles the level of adequacy and detail of existing guidelines of New England State DOTs among the key topics covered in this report.

Table 4-1. Summary of evaluation of New England State DOTs' UAS SOP or policy manual.

No	SOP Topic	VTrans	CTDOT	Maine DOT	MassDOT	RIDOT	NHDOT
1	Organizational Structure	✓	✓	✓	✓	☐	✓
2	Personnel Training Requirements	✓	✓	✓	✓	☐	☐
3	Safety Management and Operational Risk Assessment	■	■	☐	✓	☐	☐
4	Pre-flight Planning and On-site Risk Assessment	■	■	■	✓	☐	☐
5	Flight Operations - During and Post Flight	✓	✓	■	✓	☐	☐
6	Post-Flight Data Processing Workflow	☐	☐	☐	✓	☐	☐

No	SOP Topic	VTrans	CTDOT	Maine DOT	MassDOT	RIDOT	NHDOT
7	Data transmittal, retention, and privacy	✓	■	■	✓	□	□
8	UAS Emergency Procedures	✓	✓	□	✓	□	□
9	Downed Aircraft Recovery Plan	✓	□	□	✓	□	□
10	Accident Reporting	✓	✓	□	✓	□	□
11	Guidelines for Obtaining Waivers	□	□	□	□	□	□
12	Use Case Indicators	□	□	□	✓	□	□

Note:
"✓" indicates that the agency's existing guidelines adequately address the issues relevant for that particular topic to required level of detail to support UAS missions.
"■" indicates the agency's guidelines cover this topic; however, more guidelines could be added at programmatic level.
"□" indicates the agency's guidelines either does not adequately address the guidelines for the topic or refer to general guidelines or directives available under Part 107.
Note 1: MassDOT - No explicit guidelines, but Drone Team has expertise to prepare waiver applications, and has successfully obtained FAA waivers/COAs for airspace operations in class D and Boston's class B airspace, night operations, and beyond visual line-of-sight operations.

Besides the programmatic guidelines, the research also produced implementation procedures for the six transportation use cases for the New England State DOTs. Along with the UAS operation manuals, these plans are intended to act as supplementary guidelines to assist New England State DOTs in their decision-making toward selecting UAS and deploying them successfully for data collection and processing for the selected use cases. The implementation procedures are consistently divided into six stages across all the use cases, they include:

- Defining mission objectives considering alternative technologies.
- Defining system and staffing plan considering existing supply from the in-house UAS program.
- Developing flight plan and perform risk assessment.
- Obtaining required permits and waivers.
- Obtaining approval and performing flight operations.
- Assessing outcomes and documenting lessons learned.

While UAS can be beneficial for many use cases, it is essential to understand that they do not fully replace existing tools or other emerging technologies. Reviewing all options available and determining the appropriate tool for the project's goals provides the best possible data collection outcomes.

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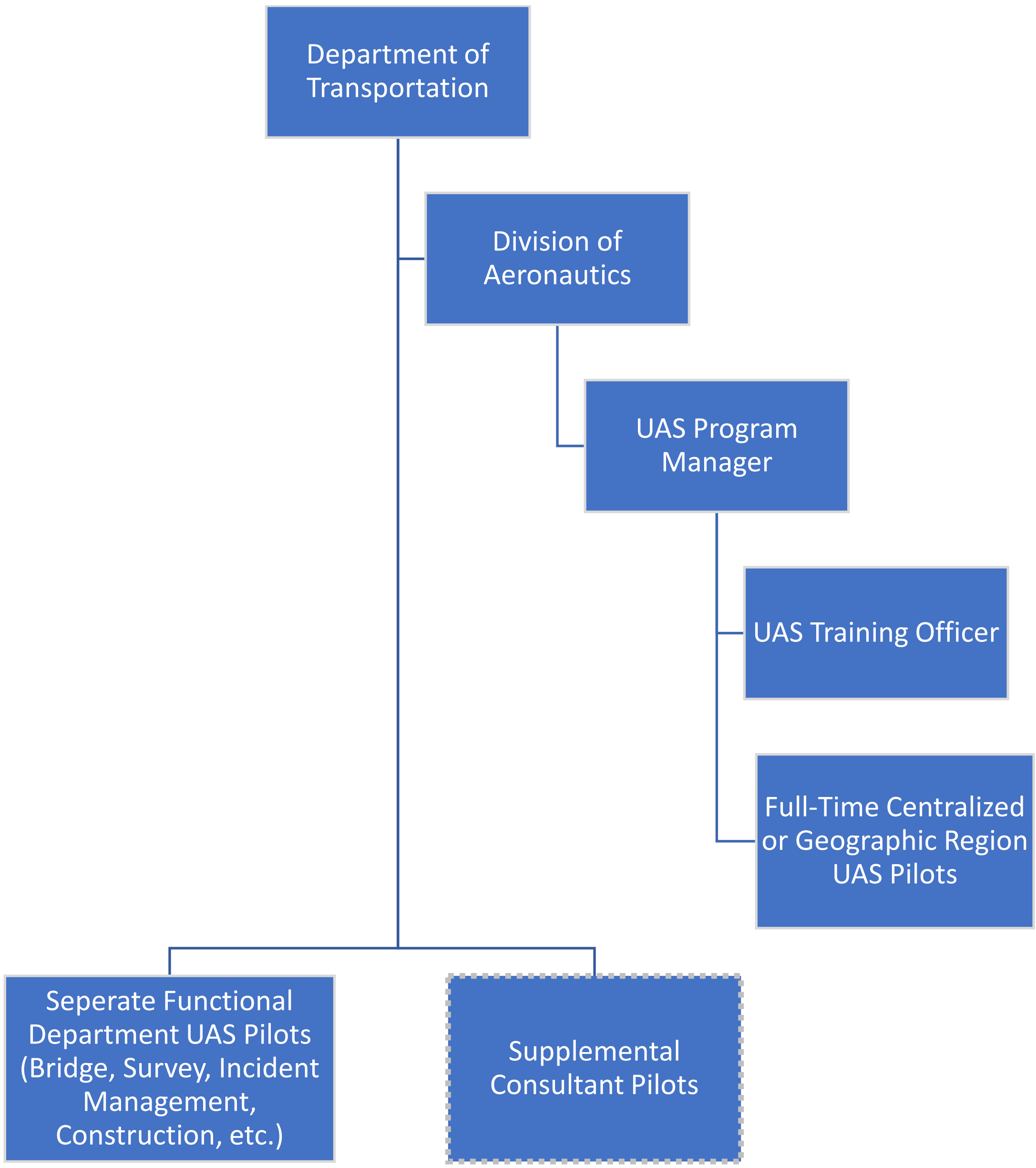
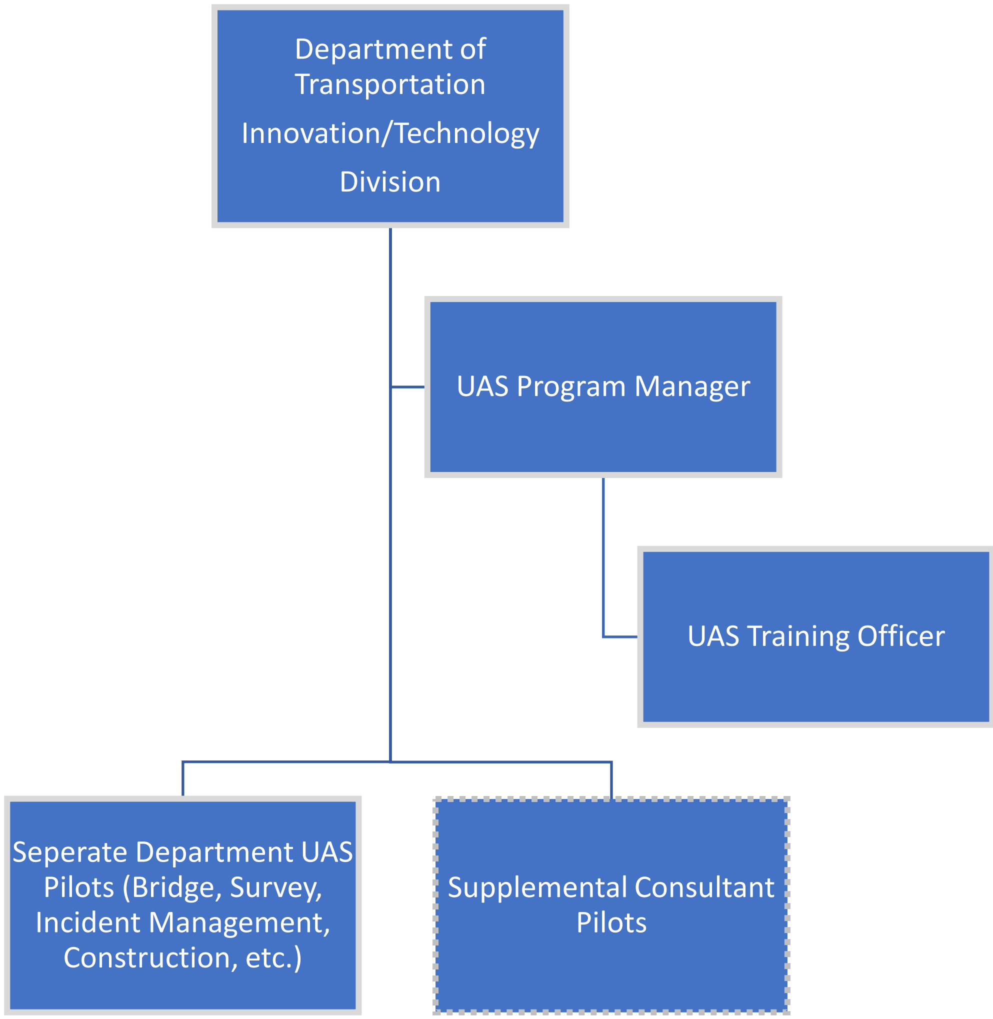
6.0 APPENDICES

6.1. UAS ORGANIZATIONAL STRUCTURES EXAMPLES

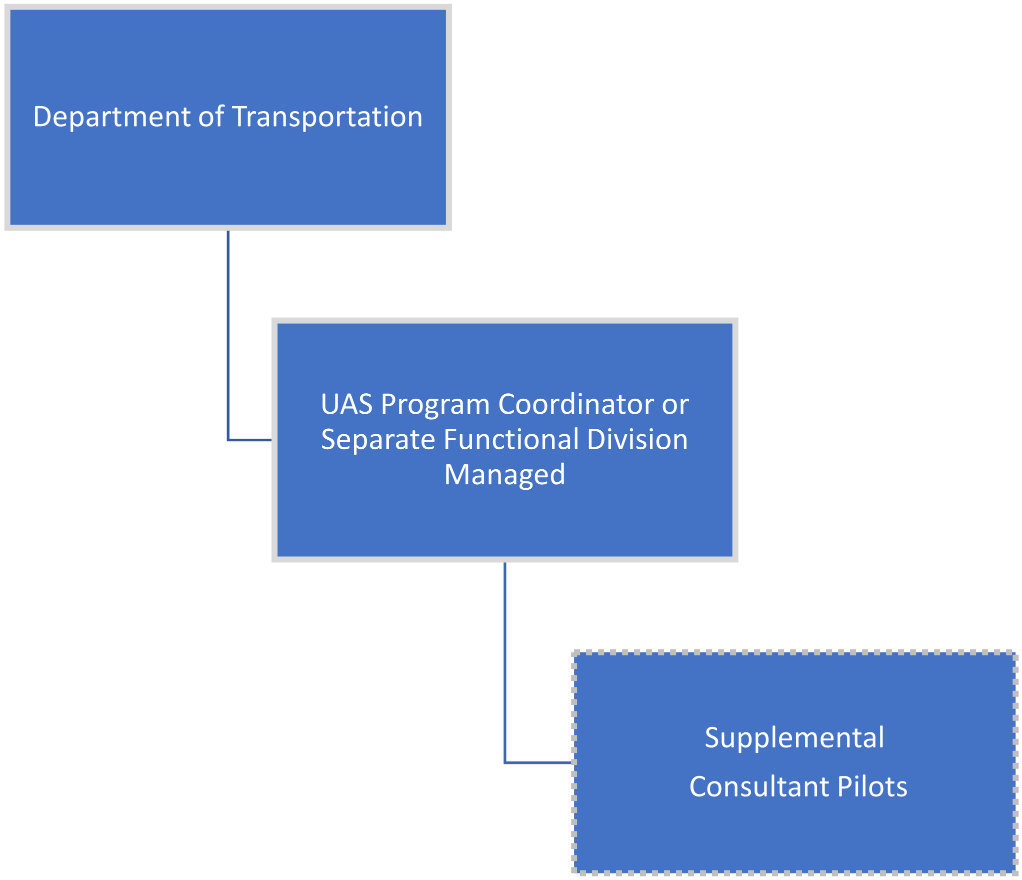
6.1.1 Division of Aeronautics UAS Program Structure



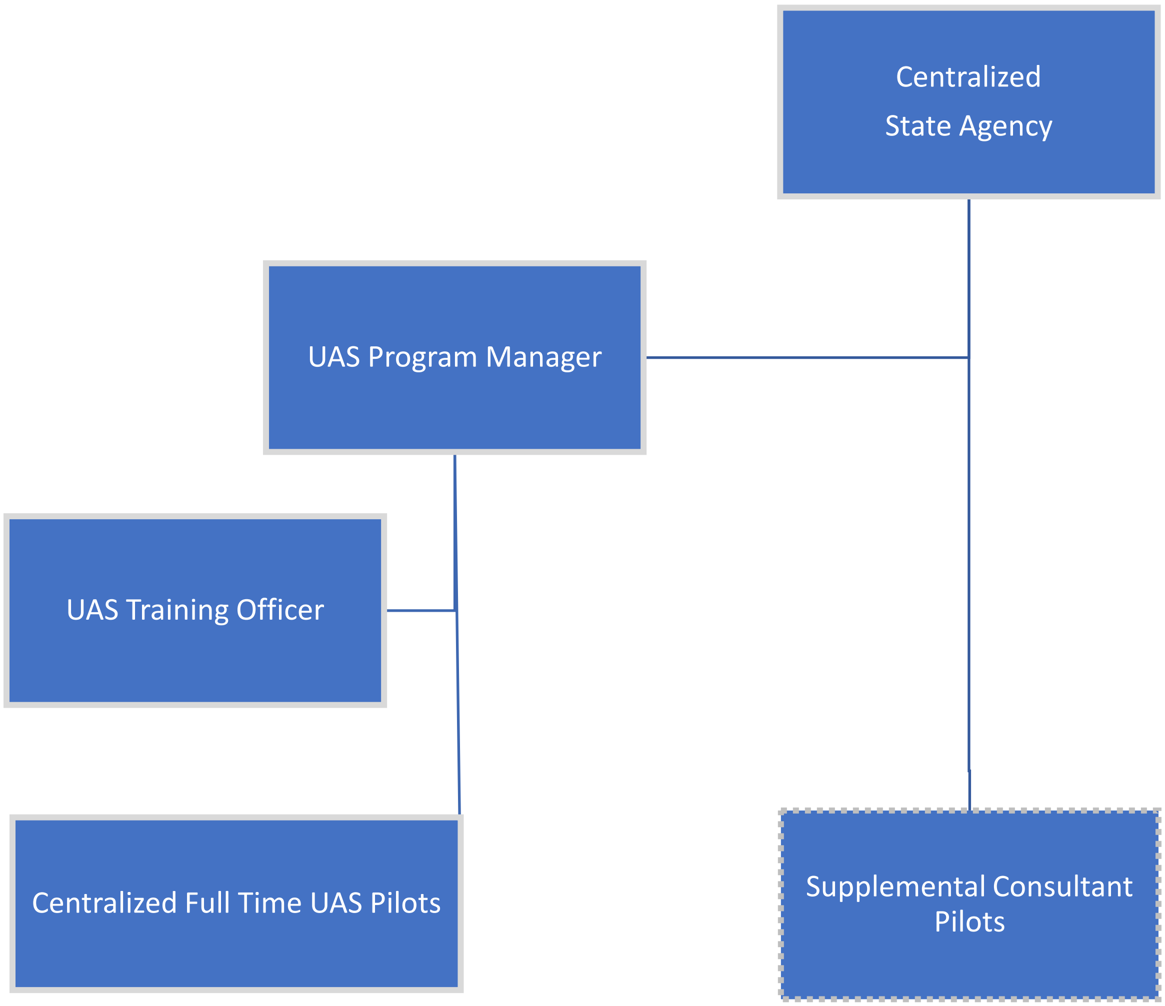
6.1.2 DOT Technology/Innovation Division UAS Program Structure



6.1.3 DOT UAS Lead – Consultant Pilots Structure



6.1.4 Centralized State UAS Program



6.2. UAS FLIGHT PLAN

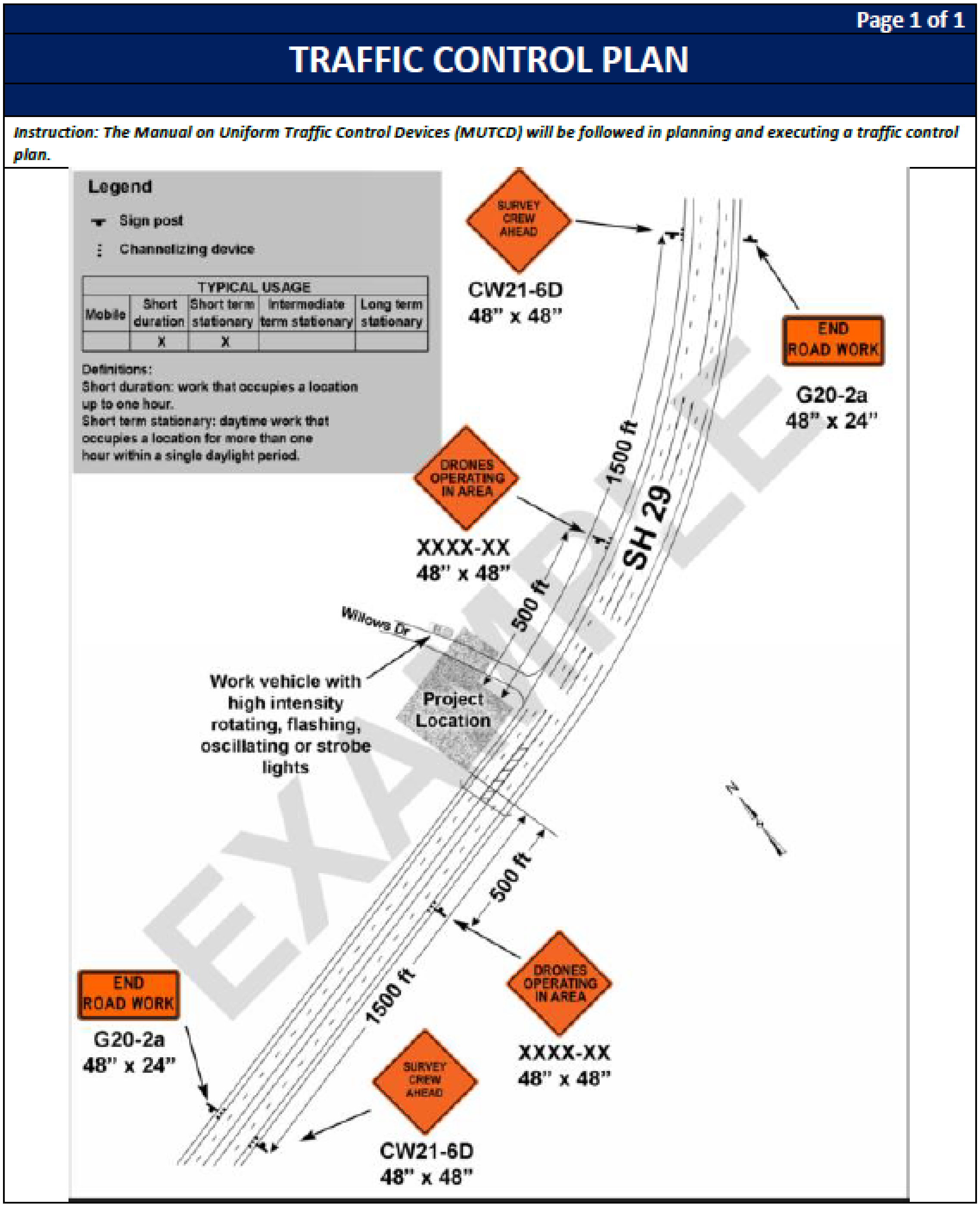
		Page 1 of 3
UAS FLIGHT PLAN		
		Project Information
Project Name:		
Project Number:		
County:		
Location (lat/long):		*Use lat/long in decimal degrees (to the ten-thousandths place)*
Project Risk Assessment (PRA) Completed:		
Pre-Approval Required:		
Projects not requiring pre-approval are flown in Class G airspace and have none of the risk factors listed in the UAS Manual. If pre-approval is required, complete and submit the pre-approval request form in addition to the Flight Plan		
Purpose of Flight		
Proposed Flight Date		
Backup Flight Date		
Maximum flight altitude to be used		
Is FAA waiver required?		
Airspace Class		
Will a NOTAM be used?		

	VDOT District Information	Consultant Services Information
Company Name:		
Contact Name:		
Address Line 1:		
City:		
State:		
Zip Code:		
Phone Number:		
Email:		

UAS FLIGHT PLAN
General Location Map
Instruction: Provide a map showing the general location of the project. Show nearby towns, roadways, airports, and other cultural features to aid in locating the project. The nearest airport (improved and/or unimproved) must be illustrated or described on the map including is approximate distance to the project location.

Source: UAS Manuals of TxDOT, Virginia DOT

6.3. TRAFFIC CONTROL PLAN



Source: UAS Manuals of TxDOT, Virginia DOT

6.4. FLIGHT CHECKLIST SAMPLE

FLIGHT CHECKLIST

PRE FLIGHT → **DURING FLIGHT** → **POST FLIGHT**

PRE FLIGHT

At office

- ☐ Aircraft Documentation
- ☐ NOTAM
- ☐ Local regulations and permissions.
- ☐ Proximity to the airport.
- ☐ Weather condition permits flying.
- ☐ All Batteries Charged
- ☐ Flight Gear check

In the field

- ☐ Scan area for obstacles, e.g. take-off and landing area.
- ☐ Wind check
- ☐ Daily Flight Report filled.
- ☐ Assemble UAV, ensure screws are tight and propeller check
- ☐ Sensor/ Camera setting check
- ☐ Batteries securely mounted
- ☐ Ensure GPS fix
- ☐ Confirm Mission flight plan
- ☐ Operators checklist (Integrated)
- ☐ RC remote check (if used)
- ☐ Final airframe inspection
- ☐ Flight Crew briefings, e.g. flight mission and safety
- ☐ Wind check again for launch.

DURING FLIGHT

After launch

- ☐ Aircraft reached safe altitude.
- ☐ Confirm observer has the aircraft in sight.
- ☐ All systems green
- ☐ Satellite and GPS check
- ☐ Check Battery remaining

Before Landing

- ☐ Ensure UAV flight done according to mission plan.
- ☐ Scan landing area for obstacles.
- ☐ Wind check
- ☐ Observer briefing for landing
- ☐ All systems green

POST FLIGHT

After landing

- ☐ Power down UAV
- ☐ Remove and safely store batteries
- ☐ Airframe inspection
- ☐ Check camera/ sensor to ensure data collected
- ☐ Transfer data and flight log
- ☐ Make logbook entry

Back at office

- ☐ Flight and Maintenance Report
- ☐ Charge Batteries
- ☐ SD card cleaned and ready to use
- ☐ Airframe checked
- ☐ Data processed

Source: UAS Manuals of North Carolina DOT, Connecticut DOT

6.5. EMERGENCY PROCEDURES CHECKLIST SAMPLE

Matrice 210/XT2--Emergency Procedures	
Ground Fire	**Response**
1. Crew & Bystanders	Alert/Clear Area
2. Motors	Disarm
3. Disconnect UAV Power	If Able
4. Fire Extinguisher	P.A.S.S.
5. Call 9-1-1	As Needed
6. Contact Management	A.S.A.P.
Flight Abort	**Response**
1. ANY "Abort"	Announce
2. Camera	Up
3. UAV	Land
Flight Abort	**Response**
1. RPIC	Announce Emergency
2. Camera	Up
3. Land	Immediately
4. UAV Power	As Needed
5. RC Controller Power*	As Needed
***Take Screen Shots if Possible for Records**	
Unplanned Auto Land	**Response**
1. Throttle	Full Power Climb
2. Flight Mode Switch	Cycle/ATTI
3. RPIC	Move Away From Potential Interference
4. Regain Comm. Signal	Attempt
If Comm. Signal Returns	***Land A.S.A.P.***
If Unable to Regain Comm. Signal	***Recover Aircraft / Evaluate Cause***
Return-To-Home	**Response**
1.RPIC	Observe Climb to Preselected Altitude
2. Aircraft	Maintain VLOS
3. Flight Mode Switch	ATTI
4. Aircraft	Manual Control
5. Controller	Check for inadvertent RTH Activation
6. RTH Function	Cancel if Active/Land

Matrice 210/XT2--Emergency Procedures	
Uncommanded Fly-Away	**Response**
1. Line of Sight	Maintain
2. Throttle	Full Power Climb
3. Flight Mode Switch	Cycle
4. Contact Management	A.S.A.P.
If Control Is Regained Go TO Emergency Landing	
Loss of GPS Satellites	**Response**
1. Flight Mode Switch	ATTI
2. Abort Flight	Execute
Lost Link	**Response**
1. Line of Sight	Maintain
2. Flight Mode Switch	Cycle
3. Controller Power	Verify On
If Controller is Off, Power It On	
4. Antenna Position	Check
5. Return to Home	Activate
If Situation Persists, Go to Uncommanded Fly Away	
Medical Emergency	**Response**
1. Safety Brief	Reference
2. Call	Call 9-1-1
3. Operator Will Need:	
Location of Emergency	
Persons Problem/Incident	
Age of Victim	
Conscious Yes/No	
Breathing Yes/No	
Battery Temperature Low	**Response**
1. Aircraft	Land A.S.A.P.
2. Battery	Remove & Replace
3. Battery Supply	Ensure They Are Warm
Battery Overheat	**Response**
1. Electrical Load	Reduce
2. Aircraft	Land A.S.A.P.
Be Prepared for Electrical Fire	

Source: UAS Manuals of MassDOT

6.6. DOWNED AIRCRAFT RECOVERY PLAN

Page 1 of 1

DARP CHECKLIST

REMAIN CALM

- ☐ Verify that all emergency response has concluded
- ☐ Verify that the downed aircraft will not cause collateral damage through fire or fluid leak

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- ☐ Send power down command to aircraft
- ☐ Secure the project site. Stow all equipment and supplies not required for the aircraft recovery effort
- ☐ Is the aircraft on public or private property?
  - ☐ Private – Contact the land owner before continuing with recovery
  - ☐ Public – Continue with recovery
- ☐ Can the aircraft be accessed safely?
  - ☐ No – contact UAS Section Manager for assistance
  - ☐ Yes- continue with recovery
- ☐ Access the aircraft
  - ☐ Power down the aircraft
  - ☐ Remove the fuel source
    - ☐ Remove the batteries
    - ☐ Close liquid fuel valve
- ☐ Document the crash
  - ☐ Take photographs, make notes and sketches as needed
- ☐ Remove the aircraft
  - ☐ Clean all debris from the site

Source: UAS Manuals of TxDOT, Virginia DOT

6.7. ACCIDENT REPORTING FORM

		Page 1 of 1
UAS ACCIDENT REPORT		
Project Name:		
Project Number:		
County:		
Location (lat/long):		*Use lat/long in decimal degrees (to the ten-thousandths place)*
Did the flight require pre-approval:		
RCIP Name::		
Accident Report *Refer to Section 2.7.1 for the minimal requirements for accident reporting. Fully explain the accident including the day, time, meteorlogical conditions and flight maneuver being conducted at the time of the incident. Describe any injury or damage cause by the accident. Include the names of any observers present. Describe any contact with law enforcement or the public. Include photographs if possible. Use additional pages as needed.*		

Source: UAS Manuals of TxDOT, Virginia DOT