New England Transportation Consortium (NETC)

NETC 18-3

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

Task 4 Report

Develop Implementation Procedures for UAS Applications

November 30, 2020

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16. Abstract Unmanned aircraft systems (UAS) technology is proving to enhance State Department of Transportation's (DOT) practices as an innovative and inexpensive solution that improves safety and accessibility, reduces cost, streamlines processes, improves workforce utilization, and accelerates several transportation operations activities. A few studies have been conducted at the national level, but little guidance has been published on incremental steps to integrating UAS in various applications. The objective of this research is to provide guidance to New England State DOTs regarding effective practices when incorporating UAS into daily operations. The fourth and final phase of this research, reflected in this Task 4 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 were then developed for six use cases based on information available from existing guidelines and case study interviews conducted with New England State DOTs. 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.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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1.0 INTRODUCTION

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 wider 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 a 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 planning and deployment of UAS for transportation applications for New England State DOTs. The report reviews existing guidelines, standard operation 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:

- Construction inspection (Connecticut DOT).
- Bridge inspection (Maine DOT).
- Surveying and mapping (New Hampshire DOT).
- Public outreach and engagement (Rhode Island DOT).
- Emergency response and recovery (VTrans).
- Traffic monitoring (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 the specific use cases and 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 not only to the members of

[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).*"

a UAS program of an agency, but also of other departments or divisions that are interested in using UAS to support their operational requirements.

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 new regulatory framework (e.g., 14 Code of Federal Regulations (CFR) Part 107) that guides and supports safe and efficient integration of small Unmanned Aerial Systems (sUAS) has created opportunities for transportation agencies to explore and deploy these tools for a variety of missions in support of their routine or special operations. Some of the common use cases explored as part of this project include application of UAS for bridge inspection, construction inspection, public outreach and engagement, traffic analysis, surveying and mapping, and emergency response.

Agencies need to dedicate resources to developing fundamental guidelines at a programmatic level to manage the safe and efficient deployment of UAS across different missions. These guidelines ensure that the stages of 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. An SOP is an important document that entails these guidelines and generally applies to all the 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 will help office staff and field crew carry out complex operations in a predictable and consistent manner and achieve operational efficiency.

This section enumerates the key topics that constitute a holistic SOP for deploying UAS for transportation operations. Each of the topics is explained based on industry best practices and is accompanied by a review of existing guidelines from New England DOTs for the particular area. Connecticut Department of Transportation (2019), Maine Department of Transportation (2020), 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, while 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 topics were identified with a primary focus on transportation sector, relevant UAS programmatic guidelines are also 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 typical functional divisions of the agency (such as Surveying, Engineering, or Construction) if the aviation division is relatively new or if the expertise to launch a UAS program exists within one of those divisions and can meet the operational requirements for various missions. The main drivers that can justify in-house (separate) UAS program include:

- Sufficient availability of staff, including remote pilots in command (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).

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 knowledge exchange and development of best practices and guidelines that are applicable broadly 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 sharing mission benefits and lessons learned.
- Availability of greater 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.

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 phases of UAS deployment. Most of the transportation agencies have a designated leader for the UAS program (such as Program Coordinator) who ensures the adoption of the SOPs and policy directives of the agency and coordinates and approves all the missions conducted by the DOT staff or consultants working on behalf of the agency. 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 should be identified to liaise with the Federal Aviation Administration (FAA) and other participating authorities at the State and local level who validates the regulations influencing the UAS program and streamlines the waiver application and approval process. Since many agencies adopt a hybrid approach (in-house and outsourcing combined) for UAS services, it is also important to identify responsible staff for handling procurement of UAS consultant-services.

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 important issue at organizational level, and 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 2-1 enumerates the essential characteristics of the UAS team members of the New England DOTs as published in their existing guidelines.

Table 2-1. 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 and shared between MassDOT and MBTA	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)	Administrator, Aeronautics Division	Policy Director	Commissioner/ Director of Aeronautics
Program Lead	UAS Program Manager	UAS Program Coordinator	UAS Program Coordinator	Administrator, Aeronautics Division	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	Not identified explicitly	Not identified explicitly	Not identified explicitly
Designated List of In-house RPICs	Identified	Not identified explicitly	Not identified explicitly	Not identified explicitly	Not identified explicitly	Not identified explicitly
Designated List of In-house VOs	Identified	Not identified explicitly	Not identified explicitly	Not identified explicitly	Not identified explicitly	Not identified explicitly
Designated Training Personnel	Training Officer	Rolls up to Program Lead	Rolls up to Program Lead	Rolls up to Program Lead	Rolls up to Program Lead	Rolls up to Program Lead

NA = Not available

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 specific objectives of the flight. 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, and additional flight currencies (that refer to the number of hours gathered from takeoff and landing flights on different modes, often with the similar aircraft platform meeting the requirements of the particular mission). This process may also include a flight test and/or written exam to demonstrate a strong understanding of the State agency's UAS policy, flight planning, and risk assessment procedures. Additional flight tests or maneuvers are also added to experience requirements especially for complex missions involving night operations, and flights over people, constrained spaces, and controlled airspace. VOs are not generally required to have mandatory certification or training requirements, although familiarity with the UAS system for the mission communication protocols (Air Traffic Control and radio communication) is often required. New England DOTs have varying levels of requirements for training programs and personnel qualifications for flying UAS for transportation applications. Table 2-2 summarizes the salient characteristics of the training program of the New England DOTs as summarized in their SOP/policy manuals.

Table 2-2. 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 prior 60 days for RPIC	SOP includes annual and recurrent training programs	SOP includes pilot eligibility training requirements Additional proficiency training within 90 days	Interim policy mentions training requirements	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	No mandatory training	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 important to ensure smoother execution across all phases, including flight operations, data collection, and post-processing. FAA's Safety Management System Voluntary Program outlines multiple dimensions to an effective safety management system that include 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 and sensor payloads checklists, insurance, and any local regulations and permitting requirements. Evaluating the mission's risk against these parameters ensures timely understanding of potential hazards and the ability to devise mitigation strategies to efficiently manage the risk before the mission moves to the field. An approval is often required from the UAS Program Coordinator (or the designee) before the operation takes place. Safety assurance consists of mechanisms put in place to enhance the predictability of the mission 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 are largely sufficient, but more advanced operations will require additional effort (JARUS (2019), ASTM F3178-16 (2016)). JARUS guidelines provide for risk mitigation not associated with safety, including property, privacy, security, and environmental risks.

- **Property:** To encourage UAS operators to follow proper rules for operations, authorities can implement measures such as restricting operations over private property and/or requiring some form of insurance to operate a UAS over property.
- **Privacy:** A common feature of small UAS is a camera (still imagery or video) payload with either on-board 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. This risk to privacy from UAS operations can be managed by regulations 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. In direct involvement, a remote pilot can purposefully fly a UAS with the intention of causing harm to persons or property by controlled flight crash landing, through deliberate interference/distraction (e.g., distraction of motor vehicle operators), or through carriage and dispatch of harmful items (e.g., munitions, chemicals). Indirect involvement includes instances of 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. A routine outcome to this event would be loss of the UAS. There is also additional risk 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/or 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 2-3 compares the safety management system (SMS) and ORA guidelines of the New England State DOTs.

Table 2-3. UAS program's safety management 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)	Commitment to develop safety policy and management plans	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	NA	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 of entry to non-VTrans space for missions	Has limited guidelines for managing ORA risks	Has limited guidelines for managing ORA risks	NA	NA	NA

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, and 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 are identified and engaged. The process often involves formally requesting a mission and obtaining approval from the UAS Program Coordinator. Most of the agencies recommend including a flight plan in the approval process that includes 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, power, 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 in charge of performing this task. The on-site risk assessment usually focuses on an examination of airspace, proximity to airports, weather, compliance with FAA regulations, project-specific characteristics (such as 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 2-4 compares the existing guidelines in the SOPs of New England State DOTs regarding the pre-flight planning. A sample of UAS flight plans and pre-flight checklists are shared in Appendix 6.1-6.3.

Table 2-4. 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	NA	NA	No direct procedures available
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	NA	NA	NA

Project Risk Assessment	VT	ME	CT	MA	RI	NH
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 pre-flight checklist (safety)	No specific procedures/ checklist provided for on-site risk assessment—SOP mentions adherence to pre-flight checklist (safety)	NA	NA	NA

NA = Not available

2.5. FLIGHT OPERATIONS – DURING AND POST-FLIGHT

Flight operations follow successful evaluation from pre-flight planning, including the 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 and normally focuses on reviewing the mission details, checklists, roles and responsibilities of the personnel, and an analysis of anticipated safety hazards and potential mitigation strategies. Subsequently, all traffic control measures and site layout (including establishing ground control points [GCPs], setting up communication equipment) are carried out according to the specific requirements of the operation, and the RPIC verifies proper functioning of the systems. The aircraft is then positioned at the takeoff area and checked for communication and power requirements. Several transportation agencies then adopt a variant of the following steps to guide the flight operations procedures on 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 "Return to Home" function is properly set for the current mission.
- The VO begins scanning 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 VTrans UAS crew help the RPIC achieve the pre-determined mission goals in a safe and efficient manner. Several flight parameters are continuously monitored, including climb rate, altitude, speed, flight path, weather (wind and temperature), and overall system health.
- The RPIC announces "LANDING" to the flight crew and observers.

After the flight, the following steps occur:

- 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 planned landing area, the aircraft, control, and communications equipment are powered down, removed from landing area, and stowed appropriately. The RPIC indicates the conclusion of the mission.
- Once the mission concludes and the project site is secured, the RPIC issues a post-flight briefing. The purpose is to review the events of the mission, discuss successes and problems, and suggest improvements for the future.
- The data collected using the onboard sensor payloads during the flight are then safely transmitted to a backup storage device for data processing.

Table 2-5 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 6.3.

Table 2-5. UAS program's flight operations for New England State DOTs.

Flight Operations	VT	ME	CT	MA	RI	NH
Pre-flight Briefing	Detailed procedure, including checklist, outlined in the SOP	Pre-flight planning and checklists provide implicit guidance on pre-flight briefing	Detailed pre-flight office and field checklists and recommends filing of flight log form	NA	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	NA	NA	NA
Post-flight Operation Procedures	A checklist of activities to be performed is included in the SOP; 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)	NA	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 control, 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 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. Establishing a holistic data management framework enables the organization to have a reliable and repeatable procedure that can be used for multiple missions. The key components are explained further in detail.

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 important to identify general stages in processing UAS data and incorporate any specific recommendations for transportation use cases. A summary of workflow is presented below (Pricope et al., 2019).

- **Global Navigation Satellite System (GNSS) Post-processing:** During data acquisition, the images are geotagged with low-accuracy coordinates from the Unmanned Aerial Vehicle's (UAV) internal consumer-grade global positioning system (GPS). The raw GPS vectors are then post-processed using RTK or PPK data and finalized for photogrammetric software. Most of the available photogrammetric software solutions provide algorithmic filters that take in raw images, GCPs, and survey-grade GPS coordinates (if used in UAV) and output a report with final deliverable.
- **Photogrammetric Software Processing:** The next step is to process the imagery to produce deliverables that may include three-dimensional (3D) point clouds, orthomosaic, and Digital Surface Model (DSM) among others. Some of the popular commercial-off-the-shelf platforms use structure-from-motion to estimate 3D structure of objects from multiple two-dimensional (2D) offset image sequences resulting from the motion of a camera mounted on the UAS. The state-of-the-art computer vision algorithm that replaces conventional stereo scoping photogrammetry technique is briefly described below.
    - 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 (SIFT), Speeded-Up Robust Features (SURF), 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 scale of the raw/original image. It is recommended to

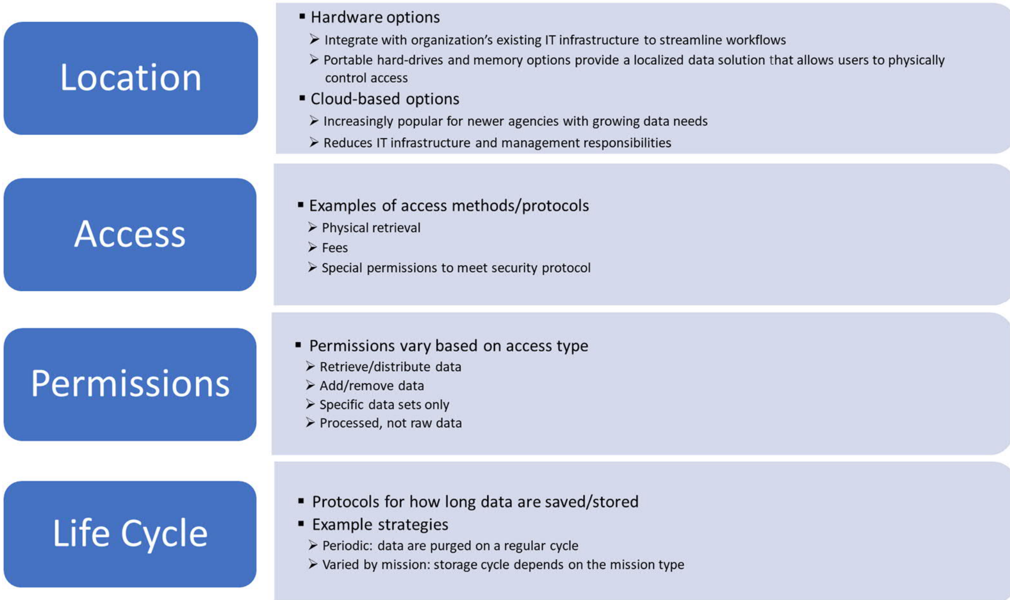
keep this value above the scale of the raw image (>1) to ensure more key points are extracted and a higher degree of confidence in the output.

  - In the next step, automatic tie points (ATPs) 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 (BBA). The generated output is usually a Low-Density Point Cloud (LDPC) that is scaled to produce High Density Point Clouds (HDPC). This scale can be customized by user (1/8-1), and it defines the relation to the original image size at which additional 3D points are generated. Finally, the HDPC is used to generate 3D textured mesh, DSM, and an orthomosaic (where the value of each pixel is calculated as average of the pixels in the corresponding original images).

- **Quality Control:** The final deliverables are often validated using quality control checks that are based on acceptance requirements of the agency for photogrammetry/UAS based products. Horizontal and vertical accuracy of the deliverables are typically used for this purpose. A general recommendation is to set threshold for 95 percent accuracy, which means that 95 percent of the checked samples from the data 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 accuracy of data collection, including collecting imagery from a lower altitude (decreased ground sampling distance [GSD]) and increasing image overlap (%). These parameters can be customized as inputs during flight planning.

2.6.2 Data Storage and Security

The four main elements of data and storage security are establishing location needs, access needs, permissions protocols, and life-cycle protocols based on the organization’s data needs (Snyder et al., 2016). The key consideration for determining the location is deciding between a hardware or cloud-based storage option. Location selection depends on the current capabilities and future goals for the organization and the UAS program as described in **Error! Reference source not found.**. 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 can they do with the data) based on roles and qualifications are important for audit and security purposes. As data needs grow within an organization, the organization should develop a well-defined life cycle to determine how long data should be saved once stored based on the purpose of the data to strike a balance between maintaining important data but ensuring obsolete data are not unnecessarily taking up storage space.



Source: (Snyder et al., 2016).

Figure 2-1. Illustration. Summary of key considerations for data management and security.

Because UAS have many complex capabilities and can quickly produce large quantities of data for processing and analysis, it is important to develop a comprehensive data management plan that considers various layers of data storage and security. If the data management protocols are not well established in advance of data collection, data quantities can quickly become overwhelming and disorganized. The agency may already have a data management policy in place 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 capabilities of the technology continue to evolve, opportunities to collect a variety of data to support various use cases increase. It is important for the flight crew to ensure only the data necessary for the mission are being collected, and any information that is inadvertently collected when the UAS is in transit is not retained. 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 is then retained, transmitted, or archived in accordance with the data retention policies of the agency. Table 2-6 compares the post-flight data processing guidelines of the New England State DOTs.

Table 2-6. 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	No specific guidelines available at the agency level	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	SOP does not include mission-specific or general guidelines on data processing	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	NA	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.	NA	NA	NA

NA = Not available

2.7. UAS EMERGENCY PROCEDURES

While normal flight procedures generally govern the steps to be followed on the day of the mission, SOPs are needed to establish the steps to be followed in the event of an emergency situation. In general, an accident report is recorded to capture the details of the emergency, and in most cases, 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 6.4.

- **Total Loss of Aircraft Power:** This case represents a situation of 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 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 important for the RPIC to expeditiously announce the emergency and land the aircraft in a designated emergency landing for the mission or a safe ditching area. Once the aircraft is powered down using remote controls, 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 hazards 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. 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 the land the aircraft immediately through the "return to home "command 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 using the "return to home" command and landing the aircraft. Subsequently, the flight parameters (e.g., heading and altitude) are noted to evaluate possible intrusion into areas that would have hazardous consequences (e.g., controlled airspace, protected infrastructure facilities). In such situations, an appropriate course of action is pursued, including contacting Air Traffic Control or 911 to manage the emergency. Once the emergency response is completed, the DARP should be carried out t
- **Bird or Fixed Object Strikes:** A bird strike can cause aircraft to lose control and crash. Depending on the extent of the 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.
- **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 this 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 emergency situations 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 emergency situations 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 Downed Aircraft Recovery Plan (DARP) represents the SOP that the flight crew needs to follow after an aircraft has crash-landed. The RPIC is responsible for implementing the 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 the aircraft, control, and communication systems are powered off. The site is then secured to recover the aircraft, and necessary data are collected for investigating the crash, including photographs and site logs. An accident report is then completed that documents the details of the crash to the best knowledge of the crew. A DARP checklist is provided in the appendix 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 case of an emergency response and collecting 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 be reported to describe the sequence of the event and help investigate potential causes behind the crash and document lessons learned. It is important for operators to be knowledgeable about the National Transportation Safety Board's (NTSB) 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, the accident report is required to include the information described below and should be submitted to the UAS Program Manager within a week to 10 days after the incident. After the details are verified, the report is also electronically submitted to the FAA Regional Operations Center (ROC), per FAA 107.9 requirement.

- 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.

An example accident reporting form is included in the appendix 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 ROC 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 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 that can enhance chances of approval. In its recent compilation of UAS operational data from the Part 107 application process, FAA indicates that detailed operational risk assessments 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 any applications, it is also useful to identify potential use cases that UAS can support on 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 on periodic basis 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. Enlisting the potential use cases in an SOP can support the development and adoption of operational-level guidelines and promote the acceptance and use of the technology across the various departments within the agency.

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 must be discussed with the UAS District Coordinator and a UAS activity subject matter expert within the agency to 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 an SOP 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 and recovery, bridge inspection, construction inspection, traffic analysis, public outreach and engagement, and surveying and mapping. 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
Connecticut DOT	Construction inspection
Maine DOT	Bridge inspection
MassDOT	Traffic monitoring
New Hampshire DOT	Surveying and mapping for highway design
Rhode Island DOT	Public engagement and outreach
VTrans	Emergency response and recovery

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. Existing program maturity of New England State DOTs and their chosen applications of interest 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 selected 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. Technologies such as UAS have made significant strides in assisting emergency responders and other key stakeholders gain access to imagery and video data of the impacted areas in a safe, timely, and efficient manner. Nonetheless, it is important to understand the objectives of the mission, assess the existing capabilities, and develop a suitable response strategy.

Step 1 – Define Mission Objectives

The first major step in decision-making is clearly articulating the mission objectives and understanding the scope of data collection necessary to assist the emergency response for various natural disasters (including flooding, wildfires, landslides, and other events). The objective of the emergency response 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 to assist in many of these situations, it is important to evaluate available alternative technologies. Some of the alternative technologies or methods include the following.

- **Aerial surveys using manned aircrafts or missions** could be useful for missions that require targeted assistance or data collection and longer flight durations. It is generally not cost-effective in comparison to other alternatives and is often inadequate for assessing damage extent and severity.
- **Remote sensing** 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 (including RGB cameras, LiDAR, infrared, multi-spectral sensors), increasing cost-effectiveness, and 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	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 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. For emergency response, it may also be necessary to coordinate with other departments within VTrans and other external stakeholders. VTrans is equipped with an Incident Command System (ICS), and the four regional commands provide an organized hierarchy of command, control, and coordination for emergency response teams with stakeholders from multiple agencies. First responders and law enforcement personnel should be 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 touchpoints of various authorities in the agency's UAS program and ICS.

System Selection: Emergency response operations normally require UAS platforms that permit higher flight durations (45 minutes) and possess good 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 livestreaming footage from drones for emergency response. The agency could consider testing and expanding its fleet to include UAVs that are connected via cellular networks (instead of 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 required work in-house, unless a mission requires specific skillsets or crew members are not available. However, the agency also noted staff availability as a major issue during case study interviews. It would be beneficial to develop and validate policy guidelines for 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 involvement of multiple agencies. Delineating 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 over people (107.39), operating beyond the visual line of sight (107.31), and operations at night (107.29), and may require permission to restrictively operate under controlled airspace. A Low Altitude Authorization and Notification Capability (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 in place 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 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 lay out 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 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. For emergency response, livestreaming of imagery or video data becomes important, and VTrans has Microsoft Streams (or other video streaming services) to support this operation. Transitioning to a desktop or cloud-based 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 collected 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 the integrated organizational structure for emergency response can also be inferred based on the effectiveness of the response operations 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, 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 ICS 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 Specific Operational Risk Assessment (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 150 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 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? • Is flight controls and monitoring checklist 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 made often in terms of technologies and dedicated public information teams to assist in this process. Timely dispensation of project information and continuous public engagement is important to ensure successful project performance especially in large and complex projects. Technologies such as UAS have made significant strides in assisting public information efforts by enabling acquisition of project images and videos for dissemination. Nonetheless, an agency needs to have a holistic implementation plan that is based on understanding the objectives of the mission, assessing the existing capabilities and constraints, and engaging a suitable deployment strategy.

Step 1 – Define Mission Objectives

The first major step in decision-making is clearly articulating the mission objectives and understanding the scope of data collection 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 important 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 required information. The underlying visual data can be collected by other technologies on jobsites such as static CCTVs 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. In necessary circumstances, it can also offer data in real-time (livestream) and to the required quality.

Step 2 – Develop System and Staffing Plan

Once it is decided to deploy UAS based on 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 nascent stages in terms of developing an in-house program with identified flight crew members and associated training requirements and guidelines. 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 roles and responsibilities of various personnel involved in the program. Developing qualification and training requirements for key flight crew members will benefit the agency during the initial stages of 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 fleets, the agency could consider developing performance specifications for the end products being delivered from consultant services. Some of the example aircraft platforms available that the agency could consider for procurement include DJI Phantom series, DJI 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 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. Rhode Island DOT could use the guidelines of the service providers and ensure it 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 also ensure a flight plan with a project map is included as part of the risk assessment.

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 deployment to collect data for public outreach efforts. Due to the nature of the operations, deploying UAS for public outreach may require waivers for operating over people (107.39) and may require permission to restrictively operate under 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. A key requirement during the pre-operation stage is conducting an on-site hazard/risk assessment before final go-ahead is given by the RPIC. Rhode Island DOT can consider developing its own 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 imageries 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 the requirements for public outreach and engagement. Metrics from UAS operations such as resolution of imageries and videos and data transmission rate (for livestreamed data) will 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 emergency response include Virginia DOT, Ohio 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 to tap up on from their UAS Working Group	Consider developing 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 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	Agency could develop SOP that offers guidelines on flight plan,	Agency can consider enhancing the existing guidelines with more inputs for Specific	• Are all the existing checklists evaluated for public outreach deployment—risk assessment,

Stage	Existing Agency Guidelines Alignment (Strengths)	Current Challenges for Deployment (Opportunities)	Key Questions for Decision to Support UAS Deployment
Risk Assessment	safety management, and risk assessment based on literature and missions completed thus far	Operational Risk Assessment (SORA)	instrument inspection (manufacturers)?
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, 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 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 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 emergency response and monitoring operations? • Are post-flight inspections and flight log reports complete?

3.3. IMPLEMENTATION PROCEDURE FOR BRIDGE INSPECTION (MAINE DOT)

Inspection of bridges plays 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. Nonetheless, it is important to understand the objectives of the mission, assess the existing capabilities, and develop a suitable response strategy.

Step 1 – Define Mission Objectives

The first major step in decision-making is clearly articulating the mission objectives and understanding the scope of data collection 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 a variety of inspections, including routine inspection, fracture critical inspection, and underwater inspection, among others. State agencies need to report on the condition of these elements 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 important to evaluate potential alternative technologies available that can be deployed to achieve similar objectives.

Inspectors often use a variety of equipment for data collection, including tools for cleaning, inspection, visual aid, measurement, high speed under clearance measurement system, remote cameras, and Tablet PCs or papers to record inspection data. Snooper trucks are often used across the country to collect the required data for various bridge elements. While often considered a standard practice, this method has multiple challenges especially regarding safety of inspectors, requirements for lane closures, and concerns regarding data granularity and accuracy.

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 (including RGB Cameras, LiDAR, infrared, multi-spectral sensors); increasing cost-effectiveness; and ability to collect data safely, in real-time (livestream), and to the required quality. It is possible to collect data used to identify various defects such as cracks and concrete delamination, among others. Table 3-5 compares alternative technologies based on several performance metrics often considered for selection at this level.

Table 3-5. 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 qualification and experience of the flight crew 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 permit higher flight durations (45 minutes) and 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 determination of condition states of each important element. This specification also plays an important role in determining sensor payloads. Maine DOT currently has two DJI Phantom 4 multicoptor drones based on specifications and software that are 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 and 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.

In general, the agency is suitably positioned to perform most of the required 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 procurement of UAS-services in case the requirement arises. The agency's UAS policy provides some guidance on procurement of UAS-related equipment and services in this regard.

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. 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 especially safety concerns arising from metallic objects in the bridge that can impact the drone's stability and 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

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 bridge inspection. Due to the nature of the operations, deploying UAS for bridge inspection may require waivers for operating over people (107.39), operating beyond the visual line of sight (107.31), and operations at night (107.29), and may require permission to restrictively operate under 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 be 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 approval process. 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. A key requirement during the pre-operation stage is conducting an on-site hazard/risk assessment before final go-ahead is given by RPIC. Maine DOT's operations manual does not contain explicit checklists for FRA. The agency could consider including checklists for risk assessment, normal procedures, and an in-flight emergency plan. Transitioning to desktop or cloud-based image processing solutions can 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 collected data is assessed against the capabilities to meet the requirements for bridge inspection. Metrics from UAS operation such as accuracy, point density, GSD, and resolution will 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 & Photnikov, 2019), Louisiana DOT (Darby & Gopu, 2018), and Minnesota DOT(Lovelace, 2018).

Table 3-6 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 3-6. 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 following issues anticipated during UAS operations in the field—wind shear, magnetic interference (metallic elements), GPS loss?
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 a common challenge. Consider procurement of UAS with autonomous flight control to provide alerts on imminent GPS loss	• 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?

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	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 SOP for pre-flight planning, risk assessment, instrument inspection Agency can consider enhancing the existing guidelines with more inputs for Specific Operational Risk Assessment (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, 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 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)?
Obtain Approval and Perform Flight Operations	Agency can consider expanding their 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 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? • Is flight controls and monitoring checklist available to use for emergency response and monitoring 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 in the forefront of adopting UAS technology because of its inherent similarity to conventional aerial mapping. The industry created a new method of aerial mapping with low cost UAS platforms equipped with high-resolution imaging sensors and LiDAR payloads. 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.

Step 1 – Define Mission Objectives

Broadly speaking, there are two methods of UAS aerial mapping. An UAS photogrammetry is a simple alternative to the conventional manned aerial photogrammetry suitable for small areas. The other method uses an 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 a common mistake 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 thick tree canopy and foliage areas where bare earth surface needs to be mapped. It can be often carried out at the same time 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 and the fundamentals of this method is translated directly to computerized process called structure from motion or sometimes it is called multi-view stereo. UAS aerial photogrammetry is suitable for small areas such as school sites, commercial construction sites and road intersection projects. It has a great advantage in mobilization and processing time and is cost efficient compared to the manned aerial photogrammetry.
- **UAS Aerial LiDAR Mapping** has advantages in small areas with 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 (Table 3-7).

Table 3-7. 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 systems and staffing plan.

Team Selection: UAS mapping missions usually require a two-person flight crew. The main pilot is responsible for the aircraft's airworthiness and the 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 environment such as roadways.

System Selection: Surveying and mapping UAS operations normally fly at a higher altitude 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 flying 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. 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 desired accuracy.

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

Flight Path Design: Flight path design is a 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 waterbodies or repeating patterns such as gravel and sand.

Ground Control Point Placement: GCP placement plays a crucial role in UAS photogrammetry and can directly affect the accuracy of the result. Poorly designed GCP placement can result severe distortions in elevation and could 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.

Step 4 – Obtain Permits and Waivers

Ensuring compliance with Federal, State, and local regulations and assessing the requirement of Part 107 waivers forms the next step in UAS implementation procedure for surveying and mapping. Due to the nature of the operations, deploying UAS for surveying and mapping may require waivers for operating over people (107.39), operating beyond visual line of sight (107.31), and operations at night (107.29), and may require permission to restrictively operate under 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.

Step 5 – Obtain Approval and Perform Flight Operations

Once regulatory permits and waivers are in place, New Hampshire DOT-designated personnel should 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 final report.

Table 3-8 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 3-8. 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?
Obtain Permits and Waivers	Current FAA Part 107 guidelines	Guidance can be added to include considerations for waiver applications, 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 surveying? • Are all the required waivers/permits obtained within 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 solution 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 has been widely adopted in bridge inspection and the surveying and mapping industry; now it has begun to be adopted in construction inspection. UAS provide valuable information for safety and integrity of the construction sites that improve the quality and the safety of the workers and the public. While it is still an early stage of adoption, it is not an overstatement to assume that every construction company owns and operates UAS in some ways.

Step 1 – Define Mission Objectives

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

Table 3-9. 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. It is used to detect and analyze changes, and aerial photographs 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: Connecticut DOT has pilot training requirements in its UAS SOP. A VO can be anyone in the construction site for the duration of the flight mission. The pilot should conduct the flight during the set schedule for site safety and awareness.

System Selection: Construction inspection is normally focused on small areas that can be covered with multi-rotor UAS platforms. 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. The visual inspection of the aerial photograph can provide sufficient information; however, full 3D modeling and orthomosaic compilation can be a benefit in construction inspection. The workflow and the system should follow surveying and mapping criteria.

Step 3 – Develop Flight Plan and Perform Risk Assessment

UAS flight plans can be significantly different based on the type of inspection flight. Visual inspection of a structure can be performed by a livestream free flight, and routine inspection flights should be done by automated scheduled flights. Livestream structure inspection flights should follow bridge inspection workflow because the flight objectives are identical. 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 includes the type of construction, the purpose of the inspection, and the inspection requirements of the construction phase.

Flight Repeatability: In construction inspection, flight repeatability is crucial to monitor any changes made during the construction. 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 ground truth points are strongly recommended to control the accuracy of the data. In an active construction site, the locations of these control points should be selected carefully. Once placed and used for control, the same control point should be used repeatedly.

Step 4 – Obtain Permits and Waivers

Ensuring compliance with Federal, State, and local regulations and assessing the requirement of Part 107 waivers forms the next step in UAS implementation procedures for construction inspection. Due to the nature of the operations, deploying UAS for construction inspection may require waivers for operating over people (107.39), operating beyond the visual line of sight (107.31), and operations at night (107.29), and may require permission to restrictively operate under 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 be 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. For routine flights, it is recommended to set a time for flight during the day for repeatability and 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 organized naming convention.

Table 3-10 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 3-10. 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	CTDOT 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	CTDOT 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 their SOP and policy manuals—no specific guidelines exist thus far	Guidance can be added to include considerations for waiver applications, 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 construction inspection? • Are all the required waivers/permits obtained within 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 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? • Is flight controls and monitoring checklist available to use for emergency response and monitoring 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 a great potential for using UAS for traffic analysis applications. UAS equipped with a high-resolution camera flying at a high altitude provide an aerial view of live traffic data, and recent advancements in computer vision can detect and analyze the speed, count, and flow, and sometimes make decisions on its own. Although there are limitations (e.g., altitude ceiling and short battery life), the prospect of UAS application in traffic monitoring is tremendous.

Step 1 – Define Mission Objectives

The advantage of UAS in traffic analysis is the wide coverage from the air. 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 3-11).

Table 3-11. 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

Once it is decided to deploy UAS based on 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.

Team Selection: MassDOT has been engaged in UAS integration across aeronautics, rail and transit, highways, and emergency management sectors. MassDOT developed a pilot program to integrate UAS technology into bridge and rail inspections that guides flight procedures and provides checklists prior to conducting a UAS flight.

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 required, a tethered system is required. Some systems can be modified to a customized tethered system, but tethered UAS vendors also provide other redundant safety nets to ensure safe operation. Currently, there are limited computer vision analysis vendors for traffic monitoring and analysis. There has been more interest in Europe for developing complex algorithms for video analysis in traffic monitoring, and the most innovative traffic monitoring software is provided by European-based companies.

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. At an altitude of 400 feet, most of the 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 the straight down view in exchange of data quality. Also, battery powered UAS is strictly limited to 30-45-minute flight time due to safety concerns. Tethered UAS can overcome this limitation, but this technology comes with the cost.

Flight Altitude: Under the current FAA Part 107 rule, sUAS flight altitude is limited at 400 feet. At 400 feet, a 20 mega-pixel full frame camera view angle is not large enough to capture large areas of traffic flow in one frame. To overcome this limitation, multiple drones can be flown with sufficient overlap for stitching process. However, this approach requires complex field operations and creates exposure to many sources of error. If there is a permanent structure such as transmission tower or a telecommunication tower, a pilot can use these structures to increase flight altitude. From a technological standpoint, ideal flight altitude should be in between 800 to 1,200 feet, depending on the resolution of the camera.

Vantage Point and Camera Angle: To overcome the altitude limitation, sUAS pilots can adjust the angle of the camera 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 30–45 minutes in air flight time. It is a common requirement to monitor traffic for blocks of time that span from an hour to four hours. Pilot can use multiple sUAS aircrafts and switch them for continuous monitoring, but approach this creates many post processing problems and additional work. Ultimately, it is ideal to have one aircraft stationary for desirable lengths of time. To achieve this purpose, tethered sUAS provide an unlimited source of power. There are tethered sUAS vendors within 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

Ensuring compliance with Federal, State, and local regulations and assessing the requirements of Part 107 waivers forms the next step in a UAS implementation procedure for traffic analysis. Due to the nature of the operations, UAS for traffic analysis may require waivers for operating over people (107.39), operating beyond the visual line of sight (107.31), and operations at night (107.29), and may require permission to restrictively operate under 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 be beneficial to support the waiver application process.

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 launch point far away from the road to comply with the regulation. If the area of interest does not fall within controlled airspace, approval from DOT should be sufficient for flying over the public area under the FAA Part 107 rule.

Step 6 – Assess Outcomes and Document Lessons Learned

Raw footage data from the UAS is extremely large, and it should be converted and stored systematically. Depending on the length and the system used, an optimum cataloging and documentation method should be studied.

Table 3-12 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 3-12. 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	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 automated sUAS system for repetitive missions	• Are adequate resources (team and system) available in-house to support the mission? Safety and UAS fleet • What are the data output and accuracy of the computer analysis tools?
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, 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, 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 agency apply for advanced waiver to increase altitude ceiling above 400’?

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 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	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 provides significant opportunities for transportation agencies to integrate these tools to support digital data collection for a variety of applications. Establishing a holistic UAS program and developing the necessary guidelines is the primary step 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 along 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.

S. 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	☐	☐	☐	☐	☐	☐

S. 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.

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 and 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.

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6.0 APPENDICES

6.1. UAS FLIGHT PLAN

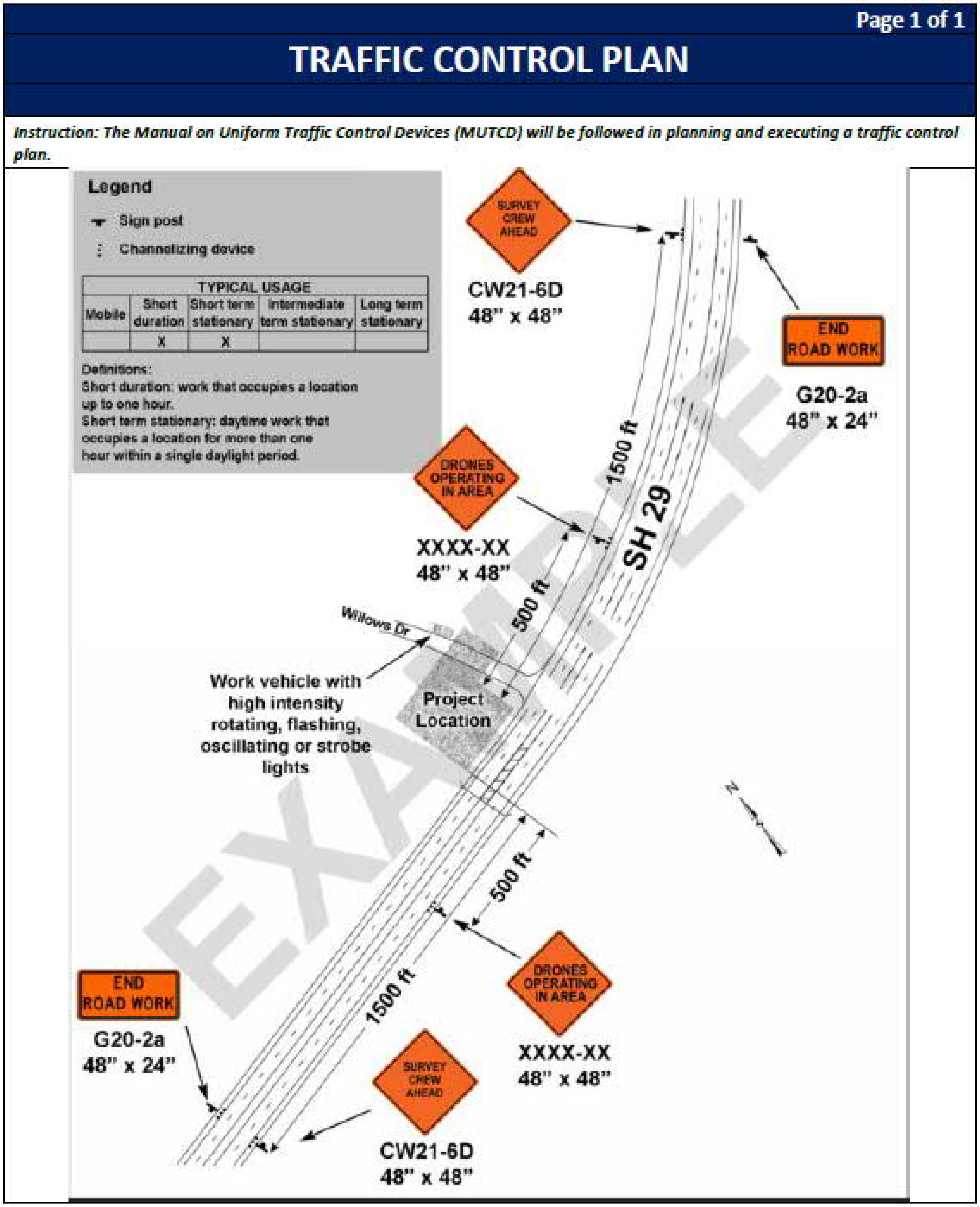
		Page 1 of 3
UAS FLIGHT PLAN		
		Project Information
Project Name:		
Project Number:		
County:		
Location (lat/long):		*Use lat/long in decimal degrees (to the ten-thousandths place)*
Project Risk Assessment (PRA) Completed:		
Pre-Approval Required:		
Projects not requiring pre-approval are flown in Class 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

6.2. TRAFFIC CONTROL PLAN



Source: UAS Manuals of TxDOT, Virginia DOT

6.3. FLIGHT CHECKLIST SAMPLE

FLIGHT CHECKLIST		
PRE FLIGHT →	DURING FLIGHT →	POST FLIGHT
At office	**After launch**	**After landing**
☐ Aircraft Documentation ☐ NOTAM ☐ Local regulations and permissions. ☐ Proximity to the airport. ☐ Weather condition permits flying. ☐ All Batteries Charged ☐ Flight Gear check	☐ Aircraft reached safe altitude. ☐ Confirm observer has the aircraft in sight. ☐ All systems green ☐ Satellite and GPS check ☐ Check Battery remaining	☐ 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
In the field	**Before Landing**	**Back at office**
☐ 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.	☐ Ensure UAV flight done according to mission plan. ☐ Scan landing area for obstacles. ☐ Wind check ☐ Observer briefing for landing ☐ All systems green	☐ 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

6.4. 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 Massachusetts DOT

6.5. 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

6.6. 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