New England Transportation Consortium (NETC)

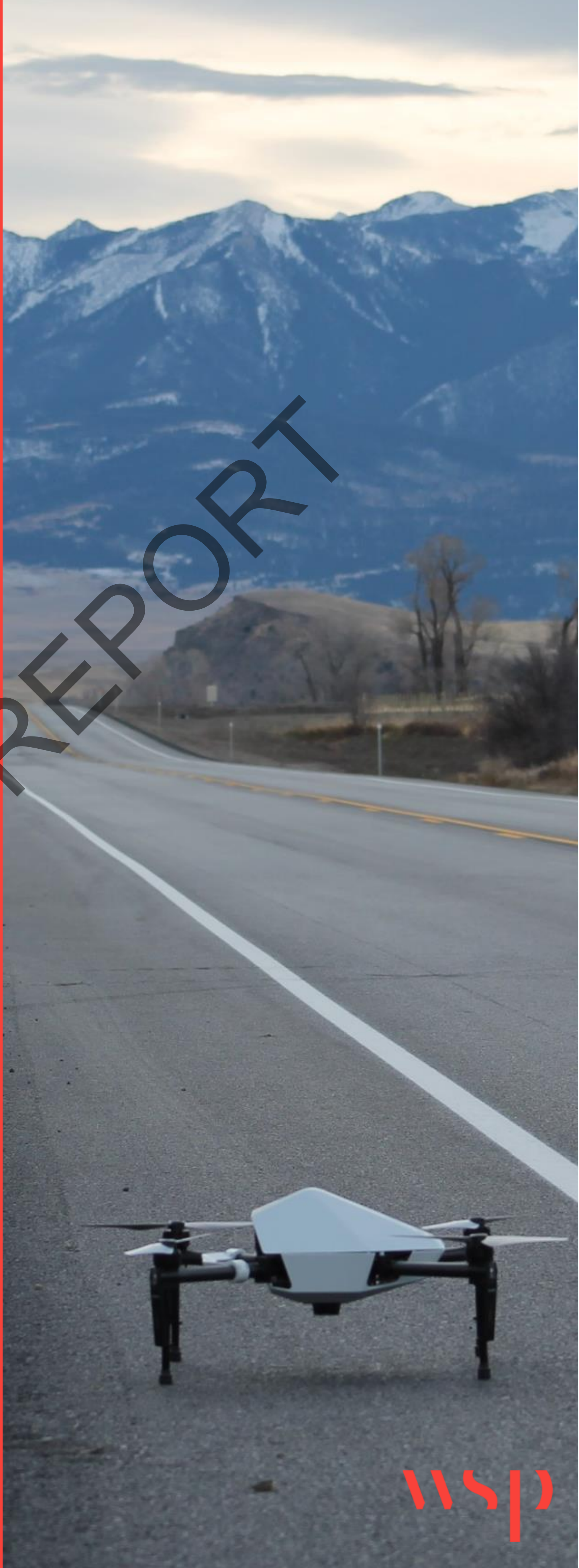
NETC 18-3

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

Task 1 Report

Exploration of UAS Applications to Support State DOT Missions

September 16th, 2019



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16. Abstract

Safety, accountability, and transparency are key guiding principles of State DOTs in their stewardship responsibilities. These principles are embodied in their mission areas to provide an effective and reliable transportation system. Unmanned aircraft systems technology is proving to enhance State DOT's 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 first phase of this research reflected in this Task 1 report provides a literature review, targeted interviews, and an analysis on the efficacy of selected transportation applications for implementing UAS technology. Subsequent phases of this research will evaluate market-ready technologies and support systems necessary to implement UAS technology, investigate traditional workflows, address challenges with regulatory compliance, and develop procedures for the selected transportation applications.

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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 aircraft systems (UAS)[1] are widely viewed as a versatile remote sensing tool for quickly capturing accurate data whether for inspection, monitoring, or general site mapping including confined space environments. Over the past several years, commercialization and proliferation of this technology has risen considerably in the transportation industry. Many service providers and departments of transportation (DOT) have come to rely on this technology in support of their missions. The applications of this technology are tightening given limitations in the technology as well as restrictions in the regulatory ecosystem. However, the technology landscape is dynamic with new capabilities being deployed seemingly every month. As illustrated in this report, those applications ripe for integration into transportation operations are plentiful and can improve DOT service areas in profound ways.

This report investigates the various applications of UAS to support DOT missions as well as the various support constructs (e.g. program components, relevant policies, and distinct New England State DOT characteristics) that enable the use of UAS. The outcomes of this report are to bring clarity to the efficacy of using UAS for certain applications, analyze the most effective uses of UAS for high-potential applications, and identify the DOT missions best served by combining UAS with traditional methods.

2.0 UAS PROGRAM COMPONENTS

State DOTs are continually evaluating the viability of creating a UAS program for their agencies, but few have dedicated resources to specific programs. In order to understand the support constructs that are foundational components to a UAS program, the research team investigated several areas including the organizational structure, competencies and training frameworks, state/legislative policies and funding, technology/data policies, safety management systems and operational risk assessments, quality management, and collaboration frameworks with partners. This section discusses in detail each of the foundational components necessary to deploy and sustain an UAS program.

2.1 Organizational Structure

The organizational structure of a UAS program is an important consideration to ensure the technology can be promulgated across perceived or actual organizational boundaries.

A recent AASHTO Survey that scanned the state of practice of UAS program at 50 State DOTs revealed that 36 out of 50 State DOTs are utilizing UAS for data collection to support various transportation applications. State DOTs have taken different approaches to organizing their UAS activities. Since UAS operations are atypical of traditional DOT functions, there has been some difficulty in staffing the UAS program. Many State DOTs have chosen to assign authority for UAS programmatic functions under their aviation or aeronautics division. During a recent peer exchange, several participating State DOTs recommended that a full staff assessment should preface any investment in additional resources because current staff may already have core competencies to enable UAS activities (Federal Highway Administration, 2018). Table 2-1 shows the organizational location of some State DOT UAS programs.

[1] For the purposes of this research, UAS refers to small UAS as defined in Title 14, Code of Federal Regulations (CFR), Part 107 (Part 107).

Table 2-1 Organizational location of UAS program. Modified from (Federal Highway Administration, 2018)

State DOT	UAS Proponent
Alabama Department of Transportation	Aeronautics Bureau
California Department of Transportation	Division of Aeronautics
Connecticut Department of Transportation	Bureau of Engineering and Construction
Maine Department of Transportation	Chief Engineer
Massachusetts Department of Transportation	Aeronautics Division
Minnesota Department of Transportation	Division of Aeronautics
New Jersey Department of Transportation	Division of Multimodal Grants & Programs Office of Aeronautics
North Carolina Department of Transportation	Division of Aviation
Ohio Department of Transportation	Ohio/Indiana UAS Center
Utah Department of Transportation	Technology Advancement
Vermont Agency of Transportation	Rail and Aviation Bureau
Washington State Department of Transportation	Aviation Division

A few state DOTs have also laid out detailed organizational structure required to be in place to establish and monitor the UAS program. Virginia DOT's draft UAS operations manual includes a proposed organizational structure clearly delineating the authorities and chain of command for agency-wide deployment of their UAS Program. It includes a UAS Program Director, an UAS Section Manager at VDOT Central Office coordinating UAS activities of VDOT field staff and consultants for various transportation applications. Figure 2-1 displays the organizational structure in VDOT's manual along with primary responsibilities of the levels of authority (Virginia Department of Transportation, 2019).

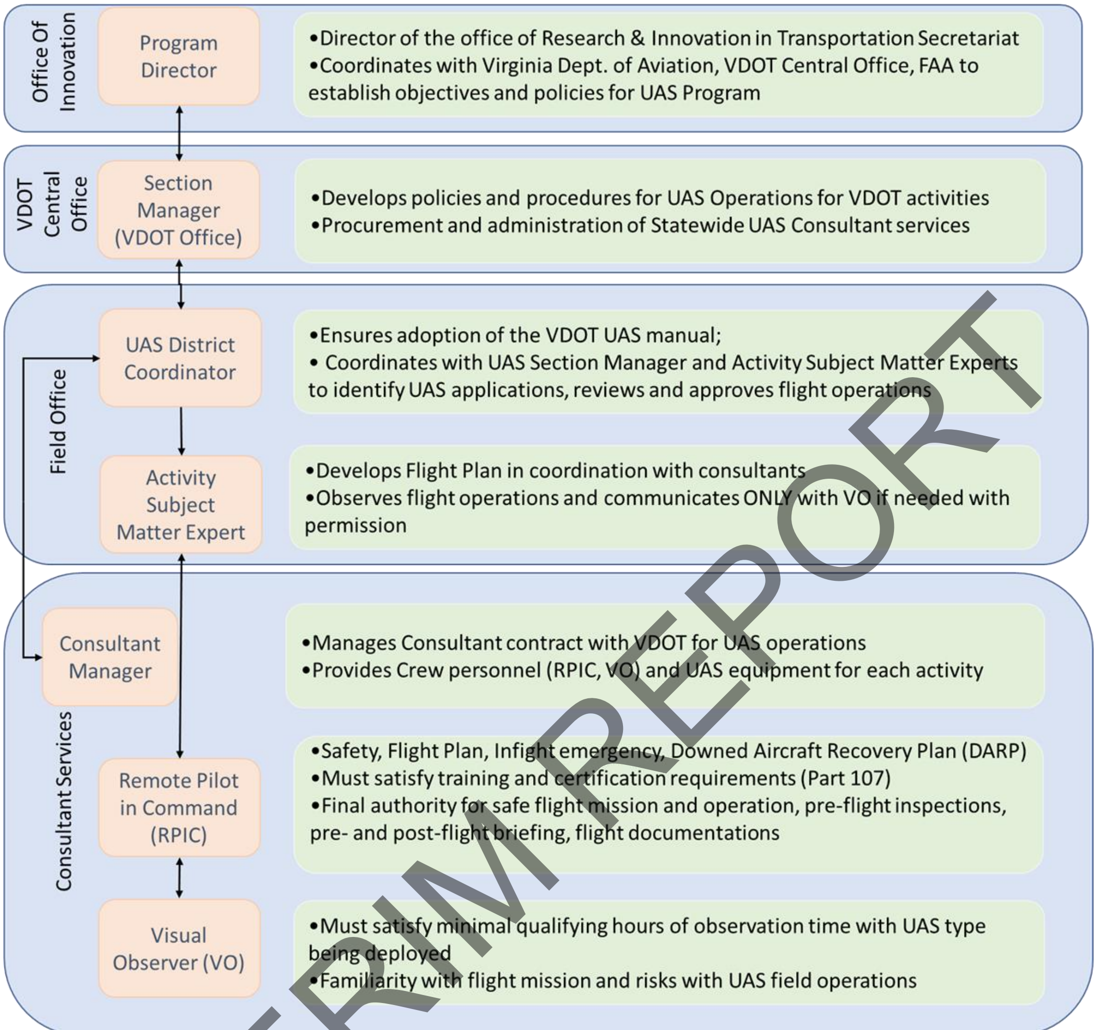
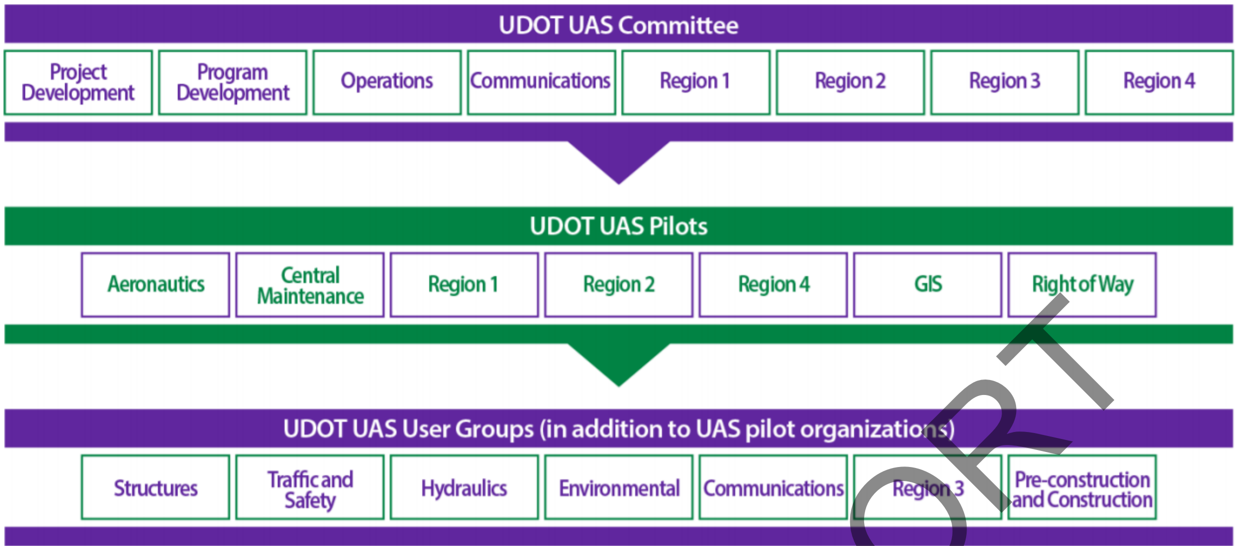


Figure 2-1 Illustration. VDOT's UAS Program - Organizational Chain of command and Responsibilities

The Alabama DOT has a more elaborate organizational structure including a Section Manager, UAS operations team (with standardized instructor operators, senior, and junior operators), UAS maintenance team (lead maintenance operator, and junior maintenance personnel), pilot in command (PIC), and visual observer (VO) carefully selected, approved, and certified by ALDOT (Alabama Department of Transportation, 2017). Furthermore, Utah DOT (UDOT) developed a unique approach to organizing their UAS activities (Figure 2-2) and enumerates the responsibilities of the following authorities entrusted with handling UAS issues for the agency within their UAS policy manual:

- Deputy Director that approves UAS requests and provides updates on UAS use to the legislature.
- UAS committee that recommends approval for UAS use requests and manages UAS procedural manuals.
- UAS Coordinator that manages agency-wide procurement of UAS, operation plans, databases of flights conducted and data recorded.



Source: Federal Highway Administration

Figure 2-2. Illustration. UDOT UAS governance structure. (Federal Highway Administration, 2019a)

Other State DOTs follow similar organizational structure and hierarchy in terms of flow of responsibilities from office to field operations. The UAS Program is structured like VDOT with minor variations at the highest level of command with the executive authority residing with Department of Aviation. Pennsylvania DOT (PennDOT) designated their Bureau of Aviation (BOA) as the lead office for establishing UAS policies and program objectives. The BOA works in collaboration with their Office of Chief Counsel to interpret federal regulations and assist with review of Certificate of Authorizations (COA) or Part 107 waivers (Pennsylvenia Department of Transportation, 2019). PennDOT also involves their public affairs office to assist with the dissemination of project information to the public as necessary. In California, the Caltrans Division of Aeronautics develops and implements processes and procedures for operating UAS in a manner that is safe and consistent with applicable statutes and regulations. In Iowa, the Office of Aviation guides the integration of UAS for Iowa DOT transportation operations. In Kansas, the Joint Task Force (JTF), led by the Division of Aviation and comprising of representation from academia, executive, and legislative departments, manages UAS integration initiatives Statewide. Similar organizational structures exist in Minnesota, New Jersey, and North Carolina.

A few state DOTs have attempted innovative approaches in developing UAS program and procurement procedures. After obtaining Section 333 exemption, the Kentucky Transportation Commission (KYTC)'s Department of Aviation completed several proof-of-concept flights and became the point of contact for questions from the public, hobbyists, entrepreneurs, and landowners. CDOT has outsourced its UAS Program since 2016 through a statewide procurement for services required for various CDOT's programs. The contracts are structured as price agreements with vendors essentially retaining equipment liability for deploying latest hardware and software and CDOT personnel focusing more on the data management aspect of the Program.

NCHRP Project 20-68 A, Scan 17-01, summarized the key strategies of a successful UAS program having a centralized authority and complete top-down support for the UAS program (Banks et al., 2018). It reiterated that a strong relationship with FAA is vital and having dedicated staff assigned to the UAS program is often required to interpret and keep up with federal, state, and local regulations.

2.2 Competencies and Training Framework

Operating a UAS for transportation applications requires skilled personnel that are specifically trained to understand specific areas of minimum aviation competencies including applicable regulations, airspace, weather information sources and related effects on UAS operations, UAS loading, emergency procedures, flight crew resource management, radio communications procedures, determining the performance of UAS, physiological/human factors, aeronautical decision-making and judgment, airport operations, and aircraft maintenance and inspections. Beyond these minimum competencies, subject matter expertise in relevant transportation operations is important so that the data being collected is contextually accurate for decision-making. The Scan report recommend the state DOTs require the following competencies/qualifications:

- Pilot in Command (PIC) is required to be certified under the Part 107 Remote Pilot's Certificate with a small UAS rating. In addition to FAA certification, Pilots have qualifying hours flying the UAS of similar type to be used in the field, with a recommended five hours of flight time for a rotary-wing aircraft and a minimum of 20 takeoffs and landing with minimum altitude of 50 feet, reaching cruise speed on all flights, for operations of a fixed-wing or hybrid aircraft. Recertification of remote pilots with a small UAS rating is required every 24 months. A recurrent test on aeronautical knowledge is required for non-Part 61 pilot certificate holders covering topics such as regulations, airspace, emergency procedures, crew resource management, aeronautical decision-making and judgment, airport operations, and aircraft maintenance and inspections.
- Demonstrate understanding of the State agency's UAS policy, flight planning, and risk assessment procedures and pass the DOT's UAS written exam as necessary. PennDOT and NCDOT requires clearing such exams for both government and commercial operators. Ohio DOT, in addition, requires knowledge in data aspects related to UAV operation such as knowledge of data processing software, video and 2D software packages, knowledge of reading and interpreting thermal data. MaineDOT and MassDOT also require specific knowledge and proficiency and have implemented training frameworks discussed in greater detail in subsequent sections.
- Complete flights with a UAS trainer and conduct solo flights with a UAS aircraft. Some DOTs require demonstration of certain maneuvers before flight operation. PennDOT for example, requires successful take-off and landing for the following flight maneuvers:
    - Maneuver vertically and horizontally around an object;
    - Maintain camera orientation on object while flying 360° around the object;
    - Fly a figure eight while maintaining camera forward;
    - Perform flight maneuvers at high altitude and at extended distances; and
    - Perform evasive and emergency recovery maneuvers.

The Scan Report recommends state DOTs establish and maintain initial and continuing training program. VDOT recommends the RPIC undergo a UAS refresher training once every 24 months following the receipt of FAA remote pilot certification and maintain relevant documentations (Banks et al., 2018).

PennDOT requires training following every 3 months of operator flight inactivity and the training will be administered by Bureau of Aviation. Interestingly, the Scan Report found that the most competent and robust training programs became part of the state DOTs that included commercial pilots in their UAS program. Other resources to become a remote pilot are also reconciled in detail and promulgated by third-party consultants, law firms, and non-profit organizations (Rupprecht Law P.A., 2019).

Some of the state DOTs have developed performance specifications for the data and left it to the contractor to use any method that complies with the requirements. Ohio DOT includes the performance criteria such as safety on jobsites, data quality, cost, professionalism, quality of operations, availability, and UAS maintenance plan.

2.3 State Policies, Legislative Priorities, and Funding

Understanding and compliance with various legislative requirements is critical to successful deployment of UAS program at state DOTs. The relevant rules and regulations for UAS operations are those enacted by the various levels of government including Federal, State, Local, County, City, and township, with Federal regulations generally overriding the requirements from State and other local entities with respect to the UAS.

The primary federal regulation influencing the non-hobby UAS operations is the FAA small UAS rule (Part 107) that was enacted on August 29,2016. Part 107 first requires that the UAS be registered either through the "FAA DroneZone Portal" or through the legacy paper-based registration process (Federal Aviation Administration, 2016). This regulation enables commercial firms seeking UAS operations for transportation applications to obtain a remote Pilot Certificate that meets the following criteria

- UAS rating generally limited to flights under 400 ft. AGL or within 400 ft. of a structure (Part 107.51).
- ground speeds less than 100 mph (87 Knots) and weight of aircraft less than 55 lbs. (25 Kg),
- Operations within visual line of sight (without an exemption) (Part 107.31),
- Daylight and civil twilight only, with minimum visibility of 3 miles (Part 107.29)
- No operations over any persons not directly participating, not under a covered structure, and not inside covered stationary vehicle (Part 107.39)
- Operations within Class G airspace (uncontrolled) with coordination required from ATC for using Class B, C, D, and E airspace (commercial airspace) (Part 107.41)

Part 107 also simplified requirements for flying UAS by eliminating the need for airworthiness certification mandated under pilot certification requirements defined under 14 CFR 61 (Part 61). Section 333 exemptions and public Certificate of Authorization (COA) request represent other avenues used prior to Part 107 to obtain permissions for UAS operations although these pathways would take as long as six months without the guarantee of an exemption being granted. They were primarily used between 2014 and 2016. Examples include exemptions granted for AerialZeus to collect remote sensing data and aerial imagery for Caltrans (June 30, 2015), KYTC's exemption for conducting aerial surveying and inspection (October 28, 2015), and Ohio/Indiana UAS Center and Test Complex (November 16, 2015).

FAA evaluates applications for waivers and Certificate of Authorizations (COAs) to deviate from some of the 107 rule sets on a case-by-case basis. The Scan report states that Waivers to §107.29 and §107.41 were the most common waivers granted to date with adequate representations from state DOTs. Iowa DOT was issued 18 waivers between November 2016 and May 2017 for Part 107.41. GDOT was issued a waiver for Part 107.29, Daylight Operation, effective 13 March 2017 with some special provisions to ensure safe operations in night time (illumination, VO presence, anti-collision lighting for UAS).

The Office of Airport Safety and Standards at FAA has provided additional guidance for airports to enhance their security through technologies and strategies for detection and countering of UAS at airports. The detection of these technologies at airport environments presents operational challenges for civil use. Nonetheless FAA rolled out the beta version of Low Altitude Authorization and Notification Capability (LAANC) in September 2018 at around 400 air traffic controls covering 600 airports to enable UAS operators automate the authorization of airspace near airports (Federal Aviation Administration, 2019) .

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

Source: Federal Highway Administration

Figure 2-3. Illustration. Order of legislative influences for UAS operations (Mallela, et al., In Press.).

2.3.1 Legislation

Most States also have some legislation impacting UAS operations. Arizona State Legislature has one-statewide law (SB 1449, 2016) that contains additional provisions to be met for use of drones in the State. Some of them include

- UAS cannot interfere with police, firefighters, or manned aircraft.
- Flying a drone in “dangerous proximity” to a person or property is defined as Disorderly Conduct.
- UAS cannot fly within 500 feet horizontally or 250 feet vertically of any critical facility. These include but are not limited to oil and gas facilities, water treatment facilities, power plants, courthouses, military installations, and hospitals.

- Cities and towns in the state of Arizona that contain more than one park must allow drones in at least one of them.
- Cities and towns in Arizona are prohibited from creating their own drone laws. The Arizona State Legislature claims pre-emption for the creation of any regulations concerning drones.

California General Assembly have passed special provisions to provide immunity for first responders if they damaged an UAS that was interfering with their services. It also imposes prohibition of an UAS entering an airspace of an individual breaching his/her privacy and familial space. Other detailed provisions concerning State laws can be found here. At Operational level, many DOTs include documentation and approval requirements for seamless planning and execution of UAS activity. VDOT and TxDOT operations require a Project Risk Assessment, A Flight Plan, A Traffic Control Plan, an in-flight emergency plan, a Downed Aircraft Recovery Plan (DARP), and procedures for accident reporting. Figure 2-4 shows the States that has legislations in place concerning use of UAS.

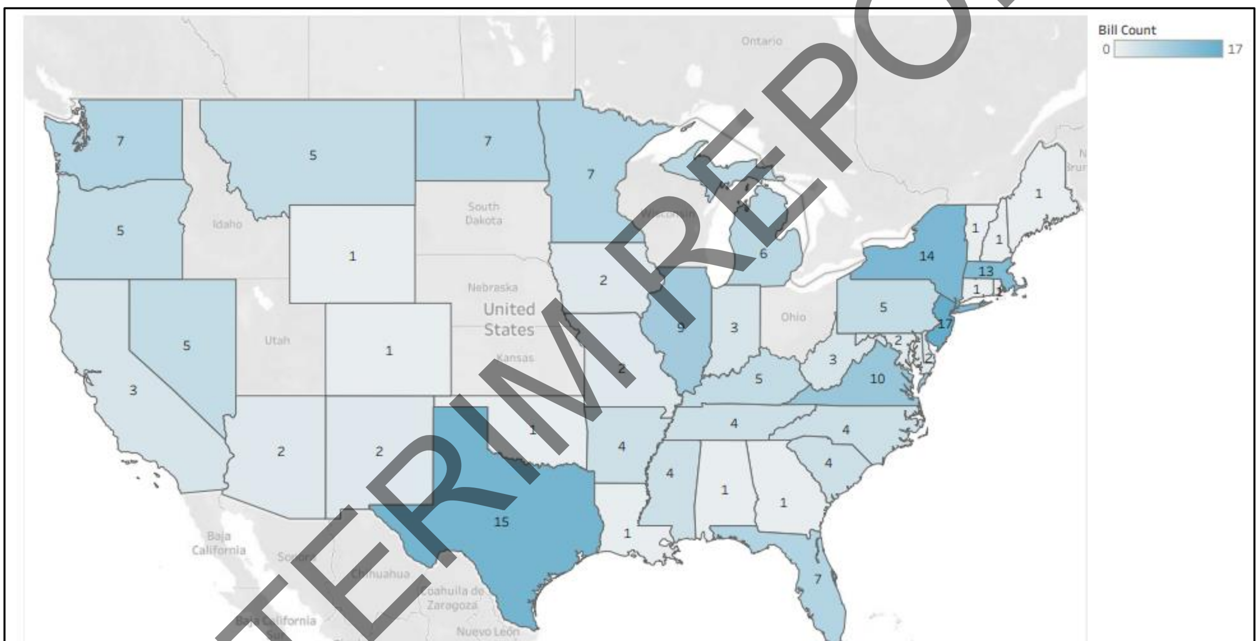


Figure 2-4. Map. States with UAS legislations/Bills.(Association for Unmanned Vehicle Systems International, 2019)

The following table is a digest of select UAS laws at the state level for the New England States, as of 2017. This list is for informational purposes only and is meant to illustrate actions taken by relevant state legislatures to enable or restrict the use of UAS. Other rules/regulations may exist.

Table 2-2. New England state UAS laws.

State	Reference	Comments
Connecticut	Public Act 17-52 (2017)	Restricting ratification/ enforcement of municipal rules unless authorized by state/federal law without conflict of Connecticut Airport Authority. (Rupprecht Law P.A., 2017e)

State	Reference	Comments
Maine	MRS Title 25 §4501 (2015)	Regulations, provisions, and minimum standards for use of UAS by a law enforcement agency. (Rupprecht Law P.A., 2017a)
Massachusetts	None	Judge in Singer v. City of Newton case ruled (conflict preempted) against including provisions to local ordinances related to UAS registration, complete UAS bans, regulating navigable airspace, and limiting "the methods of piloting a drone beyond that which the FAA has already designated". (Rupprecht Law P.A., 2017b)
New Hampshire	Title XVIII §207:57 (2016)	Restricting the use of UAS for surveilling private citizens who are lawfully hunting/fishing (not applicable to a law enforcement agency). (Rupprecht Law P.A., 2017c)
Rhode Island	Title 1 §1-8-1 (2016)	State of Rhode Island and the Rhode Island airport corporation has exclusive legal authority to regulate UAS (subject to FAA). (Rupprecht Law P.A., 2017d)
Vermont	Title 20 Chapter 205 (2018)	Restricting the use of UAS by a law enforcement agency for investigating, detecting, or prosecuting crime (other noted uses are allowed). FAA requirements and guidelines are to be followed for use of UAS. (State of Vermont, n.d.)

2.3.2 Funding

Identification of dedicated funding sources for initial implementation and continued sustenance of UAS program is critical to enhance predictability and success in UAS operations. This section documents funding strategies and pathways state DOTs utilized to establish a dedicated UAS program.

The UAS Integration Pilot Program established through a presidential memorandum for Secretary of Transportation included ten participants to test the integration of UAS in their functional requirements. Three out of the ten participants in the program were state DOTs from North Carolina, North Dakota, and Kansas. This Pilot program provided expertise and financial assistance for these DOTs to develop their UAS program. The Scan report that looked at funding opportunities for state DOTs concluded that many agencies found their initial funding in an existing operating budget or in the office's overhead budget(Banks et al., 2018).

Some state DOTs managed to partner with other relevant, external stakeholders including academic institutions and use research grants/funding for initial deployment. As an example, University of Idaho and Idaho Companies Partner to Expand Unmanned Aerial System Capabilities reported joint effort to study the State's capabilities in terms of technologies and data acquisition methods for UAS. This study was funded by Department of Commerce's Idaho Global Entrepreneurial Mission (University of Idaho, 2016). The University of Delaware in collaboration with and funding from Delaware DOT worked on a project that investigated the State's alignment for UAS integration and the factors needed to safely and efficiently integrate UASs into national airspace (Barnes & Turkel, 2017). FDOT worked with Florida Institute of Technology to conduct a proof-of-concept study to support bridge inspections (Otero, 2015).

State DOTs have also managed to obtain federal grants to support UAS implementation in their operations. With the federal innovation technology grant, Arizona DOT has acquired eight aerial UAS to assist variety of operations including bridge inspection and surveying and enhance safety and efficiency of highway project delivery and asset management. The Arizona Council for Transportation Innovation in Spring 2018 approved the use of $18,100 in federal funds (FHWA) and $4,525 in state matching funds for the new ADOT drones (Govdelivery.com, 2018). NJDOT secured funding from three grant programs of FHWA, shown below, to invest in equipment and train employees (Federal Highway Administration, 2018)

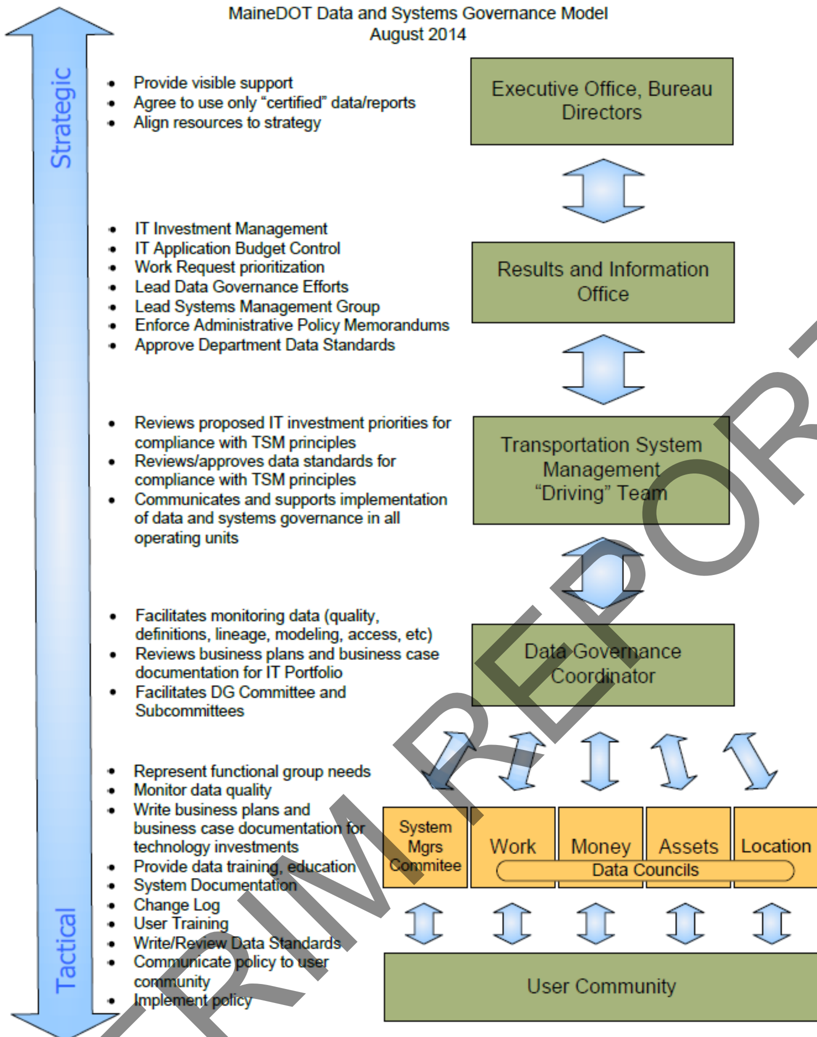
- FHWA's Technology and Innovation Deployment Program
- FHWA's State Transportation Innovation Councils (STIC) Incentive Program
- FHWA's State Planning and Research (SP&R) Program

State DOTs that are concerned with ensuring public safety can use grants available under Homeland Security/Federal Emergency Management Agency (FEMA) to purchase UAS if its intended use is to support first responders, Emergency Medical Service (EMS), and pre-disaster mitigation. The program pays only for the purchase of the customary and specialized equipment and the costs for operation and maintenance of such equipment should be usually paid through other support. Funding through this program also requires operational compliance to a COA under Section 333 or Part 107 (Federal Emergency Management Agency, 2019). An UAS program dedicated for disaster surveillance and rescue efforts could also be funded through the FEMA's Hazard Mitigation Grant Program (HMGP)

2.4 Technology/Data Policy

State DOTs have developed operation manuals and policies that has given some considerations towards governing technology and data management practices at agency-level. Montana DOT has prescribed general procedures for flight data records related to format for data storage and timeline for archival (Montana Department of Transportation, 2017). Flight log files used on construction projects should be stored permanently while all other files are retained for 3 months and deleted. Video files are stored permanently only when necessary and often transmitted to portable storage devices if they are of low importance. TxDOT has laid out recommendations in their operations manual that mandates maintaining pilot logs of all UAS flights (containing flight date, aircraft model, FAA, total number of minutes, and a general description of the flight mission). The retention timeline of records has been subjected to the agency guidelines for the same and there are no specific guidelines for archiving UAS data.

Maine DOT released their data and systems governance framework to outline their vision, resource needs and framework for data and systems governance. This framework covers all data and information used to manage the state's transportation infrastructure. The governance model (Figure 2-5) illustrates the tiers of authority along with their responsibilities. The tactical level of authority focuses on defining data quality processes and standards, providing funding recommendations, communicating policy and guidance and data use, and implementing policies (Maine Department of Transportation, 2014).



Source: Maine Department of Transportation

Figure 2-5. Illustration. Data and systems governance model (Maine Department of Transportation, 2014).

2.5 Safety Management System/Operational Risk Assessment

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

- **Safety Policy** defines the organization's commitment to safety and identifies the accountable personnel for accepting safety risks for UAS operations at office and field level. TxDOT and VDOT utilize a Project Risk Assessment (PRA) process that captures the essential project information that are relevant for UAS operations and determines whether a pre-approval is required from UAS District Coordinator for flight operations. This information includes FAA airspace classification, proximity to airports, complexity of hazards, project characteristics (e.g. traffic speed, volume, driver line-of-sight, etc.), and other alternative technologies available for consideration. Additionally, it is important to note that having insurance for UAS operations will provide liability coverage for mishaps and incidents while operating UAS for projects. UDOT's specific directives are documented in their Policy Manual and are outlined below (Utah Department of Transportation, 2017):

- UAS use will follow all requirements as listed in Part 107.
- UAS use in a manner not defined in Part 107 will obtain FAA approval through a Certificate of Waiver or Authorization (COA).
- All UAS flights require a flight plan detailing, date, time, area to be flown, altitude, and purpose of flight.
- Prior to any UAS flight the UAS maintenance log must be reviewed and accepted.
- Prior to any UAS flight the study area will be reviewed using the FAA B4UFly App to ensure flight is not prohibited in the area.
- A preflight inspection of the UAS by the pilot is required prior to takeoff to ensure the UAS is airworthy for flight.
- A post flight inspection of the UAS by the pilot is required after flight to document any problems or deviations from the original flight plan.
- Prior to use all UAS pilots will receive Department approved training on proper operation and care.
- UAS pilots must understand the Department's policy and procedures on UAS operations before flight is conducted.

- **Safety Risk Management** Procedure consists of tools and components to identify, evaluate and control the safety risks from an UAS. Typically, it involves a system analysis to identify hazards, methods to assess/quantify risks, and strategies to mitigate/manage risks. The FAA developed a hazard identification and risk assessment process chart to help UAS remote PICs analyze hazards related to the equipment being used and the environment in which the UAS is being operated. See Figure 2-6 for the process chart.

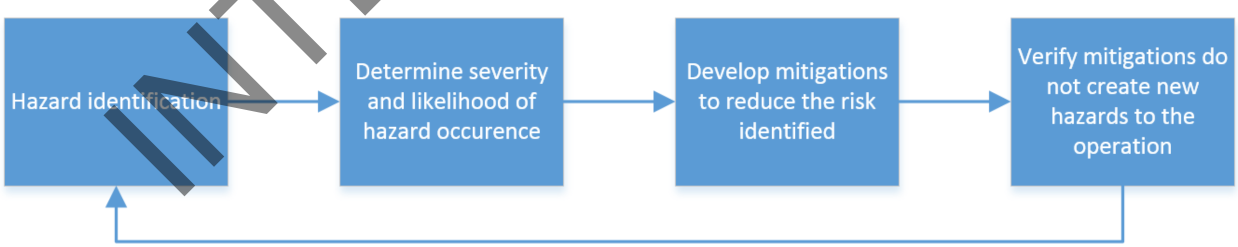


Figure 2-6. Flowchart. FAA hazard identification and risk assessment process chart. (Federal Aviation Administration, 2016a).

There are many methods and approaches to identifying hazards directly for PICs when flying UAS, but one effective method is to use a "personal minimums" checklist that covers personal hazards (e.g. illness, medication, stress, alcohol consumption, fatigue, and lack of nourishment), aircraft hazards (e.g. preflight check, UAS operational condition, etc.), environment hazards (e.g. weather, emergency mitigations, etc.), and external pressures (e.g. timing, unhealthy safety culture, awareness of true abilities, etc.) (Federal Aviation Administration, 2016a).

As part of the hazard identification and risk assessment process, measuring the severity of the hazard and likelihood of occurrence is a crucial step. Severity can be measures in terms of impact on multiple dimensions including reputation, violation, injury level, environmental damage and other factors. Likelihood can be rated ranging from the possibility risk occurring almost every UAS flight to rare occurrences. These metrics are effective in capturing the risks system-wide or program-wide. Table 2-3 provides sample severity and likelihood criteria for assessing hazards.

Table 2-3. FAA sample severity and likelihood criteria (Federal Aviation Administration, 2016a).

Severity of Consequences			Likelihood of Occurrence		
Severity Level	Definition	Value	Likelihood Level	Definition	Value
Catastrophic	Equipment destroyed, multiple deaths.	5	Frequent	Likely to occur many times	5
Hazardous	Large reduction in safety margins, physical distress, or a workload such that crewmembers cannot be relied upon to perform their tasks accurately or completely. Serious injury or death. Major equipment damage.	4	Occasional	Likely to occur sometimes	4
Major	Significant reduction in safety margins, reduction in the ability of crewmembers to cope with adverse operating conditions as a result of an increase in workload, or as result of conditions impairing their efficiency. Serious incident. Injury to persons.	3	Remote	Unlikely, but possible to occur	3
Minor	Nuisance. Operating limitations. Use of emergency procedures. Minor incident.	2	Improbable	Very unlikely to occur	2

Severity of Consequences			Likelihood of Occurrence		
Negligible	Little consequence.	1	Extremely Improbable	Almost inconceivable that the event will occur	1

Caltrans has developed a hazards identification form with checklist of 21 items that is used to evaluate and control UAS safety risks. MnDOT has used an aviation Flight Risk Assessment Tool (FRAT) that assists the agency in evaluating the UAS risks, identifies accountable personnel for approval and empowers pilot to take a final call on decision to fly. The Alaska Center of UAS Integration's Risk Analysis Workbook includes a Project Risk Assessment Matrix as shown below to identify safety risks, classify them by severity and likelihood and develop mitigation strategies (see Figure 2-7). (Banks et al., 2018)

Documentation Revision *G. Foscue* *R-1-01* *8/25/16*

Project Risk Assessment Narrative:	Ops: LOW RISK	By:	G. Foscue

The significant hazard with this project as well as most other UAS projects is the publicity/reputation hit that will occur in the event of an inflight collision with another aircraft. Hazard 9, Mid-Air Collision, cannot be mitigated to less than medium. The remaining medium hazard 3, Propulsion System Failure, is determined acceptable for this DOT infrastructure project. Flight operations will be conducted such that time spent over the pipeline will be minimized with flight routes programmed parallel to the pipeline unless it is part of a preplanned crossing.

	Hazard Analysis Workbook Summary	Initial Risk	Residual Risk
1	Loss of UAS Command and Control Link	C3	C5
2	Loss of navigational control	E2	E2
3	Propulsion System Failure	C3	D3
4	Observer loses visual contact with UA	D2	E2
5	UA Fly Away	E2	E2
6	Lost comms between UA PIC and ATC	#N/A	D5
7	Lost comms betwen PIC and observers	C4	E4
8	Loss of Link with Tracking Antenna	B2	C4
9	Mid-Air Collision	E1	E1
10	Unknown Winds Aloft	B3	E3
11	Low or bingo fuel prior to landing	E4	E4
12	Frequency Interference	D5	E5

Severity \ Likelihood	Extremely Improbable E	Extremely Remote D	Remote C	Probable B	Frequent A
Catastrophic 1	9 –				
Hazardous 2	2,4,5				
Major 3	10,14	3			
Minor 4	7,11,15	13	8		
Minimal 5	12	6,17	1	16	

Source: National Academies of Sciences

Figure 2-7. Illustration. Alaska Center of UAS Integration's project risk assessment matrix. (Banks et al., 2018)

- **Safety Assurance** consists of processes that ensure that safety risks are controlled and management measures are effective and exceed organization's objectives to identify and eliminate new hazards.
- **Safety Promotion** requires agencies to invest in training and communication of current UAS policies to its employees, any revisions to existing UAS polices, and ensuring their preparedness to manage mistakes in the field.

2.6 Quality Management

Successful UAS programs have integrated quality management activities throughout their deployment of technology including development of policies, operation manuals, and other activities related to the field operations. UAS operation manuals and policies at DOTs and other associated guidance documents should take a holistic approach to managing quality throughout programmatic and operational activities as well as mitigate procedural or policy barriers and uncertainties. The DOT should provide adequate guidelines on risk assessment, general rules for UAS operations, and bolster other planning documents to support UAS flights including traffic control plan, in-flight emergency plan, downed aircraft recovery plan (DARP), and incident management plans.

The Scan report emphasizes the significance of the training programs for UAS operations to ensure the flight procedures as well as the data collection and processing activities produce high quality results (Banks et al., 2018). It also outlines the importance of having agency commitment at executive level in championing quality management throughout the UAS program.

The FAA Remote Pilot Study Guide contains information regarding operational parameters that could influence the flight and the quality of the resulting products from the UAS operation (Federal Aviation Administration, 2016b). It provides assessment on effects of weather on UAS performance including the impact of atmospheric pressure, wind shear, temperature, clouds, icing, ceiling and general visibility. It also provides ideal specifications for aircraft characteristics regarding weight. Stability, load factors (approx. ratio between its lift and weight), and weight and balance affect the quality of the aircraft performance during flight.

2.7 Collaboration Frameworks with Partners

While UAS programs may be a core mission area to DOTs, it is common to have a support framework in place to balance workload/workforce requirements and bolster interagency collaboration. This support framework consists of partnerships with academia, consultants/vendors through procurement of goods and services, contractors, and other state agencies.

UAS goods and services are procured through an established public procurement framework at State DOTs and in accordance with the polices and regulations for general procurement at DOTs. UDOT's UAS Policy provides general recommendations concerning procurement and contracting for UAS services. UDOT procurement of an UAS owned by the agency should be approved by the Deputy Director or the designee and in accordance with the State's statutes, rules, policies and procedures (Utah Department of Transportation, 2017). Many other state DOTs (e.g. MnDOT) require the Division submit a request UAS form to District Coordinator detailing the purpose and type of aircraft, intended use and benefits. Contracting for UAS will follow similar request procedures and approval from the Deputy Director or designee and follow additional policies and procedures of the agency concerning the UAS Consultant Services.

PennDOT's procurement policies require that the District Office should contact Bureau of Aviation (BOA) for their recommendations prior to purchase of UAS equipment (Pennsylvenia Department of Transportation, 2019). Furthermore, all the employees responsible for negotiating, writing, awarding, and managing the contract must follow the DOT's procedures.

All the State DOTs require UAS purchased and owned by agency be registered with FAA and have its registration number displayed externally on UAS and the District is responsible for ensuring compliance. In addition, some state DOTs, like PennDOT, require contractors to complete registration with both FAA and the authority in charge for UAS polices within the Department (BOA for PennDOT)

The decision to fly using agency resources compared to consultant resources is a decision that should be made early in the mission planning stage. The decision support construct that facilitates this process is largely based on certain requirements including project characteristics, available resources, capabilities, and data governance. Relying solely on agency resources limits scalability, affects workload balancing, and increases agency exposure to liability, but can accelerate integration across service areas. Relying solely on consultant resources is a prudent first step with integrating UAS technology into workflows and limits agency liability, but surveilling the quality of services and deliverables should fall to a qualified agency staff in the spirit of fiduciary stewardship to the public. To retain proficiency and optimize flexibility in using UAS technology, a hybrid approach with agency and consultant resources is likely the best option.

Interagency collaboration is vital during an emergency event, so bringing comparative resources together during preparedness exercises will ensure that response and recovery activities are consistently supported by UAS technology, where needed. There are opportunities to share UAS resources beyond emergency events including public outreach and engagement, public safety, economic development, information technology governance, etc. Furthermore, partnering with neighboring state DOTs can help bolster capability maturity and advance integration efforts. Regardless of how the UAS program governance model is structured, a partnership framework is vital to its origination and scalability.

3.0 NEW ENGLAND STATE DEPARTMENTS OF TRANSPORTATION PROFILES

Throughout the transportation industry, the use of UAS technology varies widely and DOTs continue to find new applications to support their missions. These uses are driven by several factors including organization priorities and strategic outlook, the current capabilities of the organization in utilizing UAS for its operations, and areas of interest for integrating UAS technology in the future. This section provides an overview of each New England State DOT that describes agency characteristics and capability maturity levels used to identify opportunities for integrating UAS technology. This will ensure that implementation strategies are aligned with overall agency priorities and with effective practices throughout the industry. Furthermore, this information will identify areas of collaboration between the state agencies to conduct joint operations/exercises.

Table 3-1 provides a summary of each New England state DOT profile described in subsequent sections. Climate impact, agency alignment, UAS program maturity, and implementation challenges are showcased for providing a synopsis of these profile dimensions at each agency.

- Climate impact illustrates the general level of mitigation (i.e. additional batteries for cold weather UAS flights) that may be required to fly a UAS. This dimension can be minimal, moderate, or significant. The climate differences between the New England states are minimal; however, higher elevations will increase impact level given the thin air (high density altitude).
- Agency alignment illustrates the support level from agency priorities and can be weak, moderate, or strong. For example, explicit inclusion of UAS (or related terms) in agency strategies and goals would constitute a strong alignment.
- Program maturity state illustrates the perceived capability maturity level and can be ad-hoc, managed, integrated, or optimized. For example, a UAS program that has processes in place and

consistently delivers on expectations has achieved a “managed” state of maturity. A program that is “integrated” has alignment with agency objectives, processes are documented, and is measuring performance against defined metrics. (Federal Highway Administration, 2016a)

Table 3-1. Summary of New England state DOT profiles.

State DOT	Climate	Agency Alignment	UAS Program Maturity	Implementation Challenges
CTDOT	Moderate	Moderate	Ad-hoc	Ensuring proper credentialing and training
MaineDOT	Moderate	Moderate	Ad-hoc	Defining training, understanding technology advancements, and defining procurement specifications.
MassDOT	Moderate	Strong	Managed	Establishing UAS program vision for the agency.
NHDOT	Moderate	Moderate	Ad-hoc	Securing management support.
RIDOT	Moderate	Moderate	Ad-hoc	Securing management support and defining IT infrastructure requirements.
VTrans	Moderate	Strong	Ad-hoc	Procurement of hardware and software while staying nimble for technology advancements.

3.1 Connecticut Department of Transportation

Connecticut DOT’s capital program is worth $11 Billion (FY 2017-2021) with 58 percent being spent on highway and bridge infrastructure improvements, 40 percent planned to be spent on public transportation and the rest to be disbursed for general facility improvements. The agency manages approximately 3719 centerline miles of pavement that carry 87% of vehicle traffic, over 4,016 bridges, 2,783 traffic signals and 1625 Sign supports (Connecticut Department of Transportation, 2018b)

CTDOT generally relies on funding from several sources including Federal, highway trust fund, state bonding (Fix-it-first Road and Bridge Programs), and other innovative state legsilative initatives such as 2015 Legislative Let’s Go CT! Ramp-Up initiative (Connecticut Department of Transportation, 2018a)

3.1.1 Climate

UAS operations are generally sensitive to climate conditions such as precipitation, cold temperatures, windy conditions, etc. Based on available information from 2018, the climate characteristics for Connecticut are shown in Table 3-2. It can be inferred from this climate data that weather-resistant mitigation measures would bolster the use of UAS technology year-round including purchasing weather-resistant UAS hardware, purchasing/cycling additional batteries to balance battery discharge capacity, and implementing acclimation protocols for hardware (to avoid condensation build up on sensor payloads). Operating UAS at higher altitudes will impact UAS performance and durability.

Table 3-2. Connecticut climate data for 2018 and elevation data. (National Oceanic and Atmospheric Administration, 2019)

Measure	Data
Average wind speed	7 mph
Average wind gust speed	23 mph
Average maximum 5-second wind gust speed	56 mph
Average annual precipitation	54.71 inches
Average days of precipitation > 0.1 inch	87 days
Average maximum precipitation	2.72 inches
Average minimum temperature	-7° F
Average temperature	52° F
Annual clear/scattered cloud sky conditions[2]	165 days
Highest/lowest elevation	2,380 feet/ Sea Level

3.1.2 Mission, Vision, and Goals

The mission of Connecticut DOT is to provide a safe and efficient intermodal transportation network that improves the quality of life and promotes economic vitality for the State and the region. The values embraced by the agency to guide its pathway to achieve its mission include (Connecticut Department of Transportation, 2019)

- Technology-driven preservation of integrity of asset for safe and efficient multimodal transportation
- Open and transparent decision-making and information sharing to support excellent customer service.
- Enhanced quality of life through commitment to maintaining character of communities and ensuring responsible and sustainable growth
- Commitment to safety and preservation while managing and allocating human and financial resources.
- Continuous evaluation of mission, values, performance, and priorities to reinforce the importance of being innovative and responsive to changing needs

3.1.3 Strategic Priorities

The Department's Strategic Five-Point Action Plan to address systemic challenges also identifies the system maintenance in State-of-Good repair as its highest priority followed by ensuring safety and modernization of assets. The Agency's Transportation Asset Management Plan indicates the necessity to incorporate changes into the business practices and develop implementation plans that capture the landscape of changing technologies.

[2] Day and night. Weather station observation records without sky condition data were retained for chronological integrity. There was no indication why sky condition data was not recorded for some observation times.

While the agency does not identify UAV explicity as a game-changer in planning level, it has engaged UAV in pilot efforts for performing visual bridge inspection as part of its ongoing mission to improve and evaluate its operations and determine its usefulness and functionality.

3.1.4 Unmanned Aircraft System (UAS) Operations

In August 2016, CTDOT had recorded its first official use of UAV using a consultant. In May 2019, they had performed the first in-house flight using its staffs. The agency had since then reported to have developed an UAS policy and a Standard Operating Procedure for enabling consistent and safe operation of UAS by its staffs and contractors using an UAS on behalf of the department (although they are informal languages). Besides meeting the requirements of Part 107 and FAA Advisory Circular 107-2. The State of Connecticut also necessities adherence to SB 975 (2017) law that empowers a municipal water company to enact ordinances that regulate or prohibit use of UAS over the facility's water supply and land, and DEEP $23-4-1 (2017) that prohibits use of UAS in Connecticut State Parks, State Forests or other lands under the control of Department of Energy and Environmental Protection, unless specifically authorized by the Commissioner in a Special Use License (UAV Coach, 2019a).

3.1.5 UAS Program Structure

The Chief of the Department's Bureau of Engineering and Construction will designate an UAS Program Coordinator (PC), who will then administer the UAS Program across the agency and ensure the flight missions conducted by, or on behalf of, the Department adheres to procedures outlined in the SOP and other relevant directives or policy documents. The Bureau also has 2 FAA Certified Remote Pilots with UAS ratings to assist operations in-house. Currently, there is one full-time equivalent (FTE) staff for the Connecticut DOT UAS program who is assisted by other personnel as needed.

3.1.6 Implementation Challenges

CTDOT points out that ensuring the pilot has appropriate FAA certification with UAS rating on all project sites has been one of its key implementation challenges. Ensuring proper insurance/coverage for UAS activities by consultants/contractors, managing liability, and addressing privacy concerns remain other primary issues.

3.1.7 UAS Program Funding

Currently, the agency does not dedicate funding for a UAS program.

3.1.8 UAS Equipment and Software

While the agency permits their consultants to operate their own UAS to meet certain needs, recently, they have purchased two drones for in-house operations.

- Two - DJI® Phantom 4 (multicopter)

The following software packages are used to support Connecticut DOT UAS operations:

- Equipment-related software for flight operations and data collection.
- DroneLogBook – mission planning, compliance and maintenance reporting, and custom forms.

- Other standalone image and video editing software.

3.1.9 UAS Training

Currently, Connecticut DOT does not have dedicated training manuals for flight crew members and data processing technicians. The legal framework outlined in the FAA Part 107 and pertinent state laws govern the training requirements for Remote Pilot, flight crews and other members of the program

3.1.10 Transportation Applications and Priorities for Integrating UAS Technology

Some permitted uses include (but are not limited to) photogrammetry/3D modeling, aerial photography (topographic/bathymetry), construction inspection, emergency response, environmental analyses, slope failure analysis, and confined space inspections. The high-priority applications for CTDOT are as follows:

- Bridge maintenance and structural inspection. Currently, consultants are being used to provide UAS services in support of their maintenance inspections.
- Aerial mapping. The agency currently uses UAS technology for topographic mapping for material stockpile for construction projects and maintenance operations.
- Monitoring traffic and safety operations
- Public outreach and engagement efforts

3.2 Maine Department of Transportation

Maine DOT employs approximately 1,900 people and expends or disburses more than $800 million per year to deliver its responsibilities and obligations. Maine DOT has nearly 18,000 lane miles that carry 80% of vehicle traffic, over 2,970 bridges, six commercial airports, and over 490 state-owned track.

Maine DOT generally relies on funding from several sources including Federal, highway trust fund, state bonding, multimodal state funding, grants, and municipal partnerships. Nearly 60% of their funding is spent on highway and bridge captial projects, 27% spent on maintenance and operations, and the remaining spent on other activities (Maine Department of Transportation, 2019b).

3.2.1 Climate

UAS operations are generally sensitive to climate conditions such as precipitation, cold temperatures, windy conditions, etc. Based on available information from 2018, the climate characteristics for Maine are shown in Table 3-3. It can be inferred from this climate data that weather-resistant mitigation measures would bolster the use of UAS technology year-round including purchasing weather-resistant UAS hardware, purchasing/cycling additional batteries to balance battery discharge capacity, and implementing acclimation protocols for hardware (to avoid condensation build up on sensor payloads). Operating UAS at higher altitudes will impact UAS performance and durability.

Table 3-3. Maine climate data for 2018 and elevation data. (National Oceanic and Atmospheric Administration, 2019)

Measure	Data
Average wind speed	6 mph
Average wind gust speed	24 mph

Measure	Data
Average maximum 5-second wind gust speed	51 mph
Average annual precipitation	47.12 inches
Average days of precipitation > 0.1 inch	85 days
Average maximum precipitation	2.57 inches
Average minimum temperature	-16° F
Average temperature	44° F
Annual clear/scattered cloud sky conditions[3]	167 days
Highest/lowest elevation	5,276 feet/ Sea Level

3.2.2 Mission, Vision, and Goals

The mission of Maine DOT is to responsibly provide the customers the safest and most reliable transportation system possible, given available resources. The goals Maine DOT has set forth include the following (Maine Department of Transportation, 2018):

- Effectively manage Maine's existing transportation system for safety and effectiveness within reliable funding levels.
- Sensibly invest available resources to support economic opportunity for their customers.
- Demonstrate their core values of integrity, competence, and service, both individually and organizationally.

3.2.3 Strategic Priorities

The recently released work plan for 2019, 2020, and 2021 reflects two relevant priorities of Maine DOT including safety and innovation (Maine Department of Transportation, 2019b) . Safety performance will be improved through data-driven analysis and mitigation of hazards. Maine DOT also recognizes that innovation is required to help meet the needs and demands of the transportation system.

Consistent with Maine DOT's goal for managing the existing system, Maine DOT has developed ten key asset management strategies to drive their asset management program including finalizing and implementing asset inventories, condition assessments, and corridor management strategies and develop short and long-range funding Strategies for each asset type to minimize life-cycle cost (Maine Department of Transportation, 2019c). MaineDOT believes UAS technology could become a key part of achieving these objectives.

3.2.4 Unmanned Aircraft System (UAS) Operations

In 2018, Maine DOT started using UAS on their projects. In April 2019, Maine DOT published their standard UAS policy to provide uniformity for Maine DOT employees and third parties using UAS on behalf of the Department. Maine DOT permits the use of UAS by their employees and third parties for the purpose of conducting business for the Department. The UAS Coordinator, Pilot in Command (PIC),

[3] Day and night. Weather station observation records without sky condition data were retained for chronological integrity. There was no indication why sky condition data was not recorded for some observation times.

Visual Observers (VOs), and any other personnel involved in UAS flight operations are required to follow procedures outlined in Maine DOT's Standard Operating Procedures document, Part 107, and FAA Advisory Circular 107-2. The UAS Coordinator reserves the right to deny any proposed UAS flight operation if operational risk exceeds acceptable tolerances or the operation will violate FAA regulations or Department policy. UAS policy, guidelines, procedures, and implementation are reviewed annually.

3.2.5 UAS Program Structure

The Chief Engineer (or designee) serves as the Maine DOT UAS coordinator. The UAS unit is comprised of those personnel approved by MaineDOT Bureau/Office Directors and includes PICs, VOs, and others deemed necessary and have assignment as part of the UAS crew. Assignment to the UAS flight crew is selected by MaineDOT from specially trained staff members of MaineDOT with knowledge of the airspace within which the operation will take place and how that airspace fits into the National Airspace System (NAS). All PICs are required to hold FAA Part 107 certification and valid training hours prior to operation of the UAS. Currently, there are no dedicated full-time equivalent (FTE) staff for the Maine DOT UAS program. However, Maine DOT does have approximately less than five FAA-certified remote pilots with small UAS ratings.

3.2.6 Implementation Challenges

Maine DOT recognizes that the biggest challenges with implementing a UAS program are understanding and defining training requirements, keeping up with the technology advancements, and establishing equipment specifications for competitive procurements.

3.2.7 UAS Program Funding

Currently, Maine DOT does not dedicate funding for a UAS program.

3.2.8 UAS Equipment and Software

Maine DOT owns the following fleet of aircraft:

- Two - DJI® Phantom 4 (multicopter)

The following software packages are used to support Maine DOT UAS operations:

- 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.
- Other standalone image and video editing software.

3.2.9 UAS Training

Maine DOT provides a framework for their training activities in their standard operating procedure manual including instructor responsibilities, training plans, initial training requirements, and recurrent training requirements (Maine Department of Transportation, 2019a). Maine DOT believes the key to continued safe operations is by maintaining a professional level of competency starting with establishing minimum qualifications for selecting members, and then providing training.

Instructor duties are designated by the UAS Coordinator. Also, other instructional materials deemed necessary for safe UAS operations are determined by the UAS Coordinator and will be administered at their discretion.

All members have a training plan on file that outlines training objectives for the upcoming year. This training plan will be held in conjunction with the member's normal training file per Maine DOT policy. The approved training plan is developed by the UAS Coordinator. All deployments or exercises are documented and count toward a member's training requirements and it is the member's responsibility to verify their training file is complete and up-to-date.

Initial training requirements defined by Maine DOT cover both observers and pilots. Observers must have completed sufficient training to effectively communicate with the pilot any instructions required to remain clear of conflicting air traffic. This training, at a minimum, shall include knowledge of the rules and responsibilities described in 14 CFR 91.111 (Operating Near Other Aircraft), 14 CFR 91.113 (Right-of-Way Rules – Except Water Operations), and 14 CFR 91.155 (Basic VFR Weather Minimums). Furthermore, observers are required to have knowledge of air traffic and radio communications (including the use of approved ATC/pilot terminology) and knowledge of appropriate sections of the Aeronautical Information Manual. In conjunction with fulfilling all training requirements for PIC/observer duties, new members must also become familiar with UAS operations, the aircraft, and its equipment. Any new member who fails to successfully complete the initial training may be not be allowed to become a member of the UAS flight crew.

Before a member can fly as an PIC, they must complete training before operating the aircraft and obtain FAA Part 107 certification through an approved testing facility. They must also demonstrate their ability and knowledge of the UAS through sufficient training in operating the aircraft safely and effectively, as determined by the UAS Coordinator.

Recurrent training requirements are meant to ensure all members within the unit maintain proficiency in their PIC/observer abilities. Recurrent training is not limited to actual operating/observer skills but includes knowledge of all pertinent UAS/aviation matters. Failure to prove proficiency can result in removal from UAS responsibilities.

3.2.10 Transportation Applications and Priorities for Integrating UAS Technology

Some permitted uses include (but are not limited to) photogrammetry/3D modeling, aerial photography, infrastructure inspection, environmental analyses, slope failure analysis, confined space inspections, disaster response, and training exercises. The high-priority applications for Maine DOT are as follows:

- Bridge maintenance and structural inspection. Currently, consultants are being used to provide UAS services in support of their maintenance inspections.

- Aerial mapping. MaineDOT currently uses UAS technology for topographic mapping for stockpile sites. Bathymetric mapping requires sensor payloads that are currently cost prohibitive for the agency.
- Emergency/incident response. Maine DOT is planning for the use of UAS technology in support of their emergency response activities (natural and human-caused).
- Other planned applications or applications with perceived value to Maine DOT include public outreach and engagement, inspection of confined spaces, environmental assessments, and slope stability along rivers.

3.3 Massachusetts Department of Transportation

MassDOT employs around 10,000 employees with its highway Division Capital Program worth annually around $1.3 Billion. The Highway Division of MassDOT has nearly 9,600 lane miles and captal responsibility of over 5,000 bridges owned by the Commonwealth and by municipalities. MassDOT also owns seven tunnels and approx. 5000 culverts , 250,000 signs and 1,531 traffic signals (Massachusetts Department of Transportation, 2018).

MassDOT obtains its funding for transportation programs through a variety of federal sources, State funds and grant programs ,and private funding enabled through various Foundations and Iniatives (Massachusetts Department of Transportation, 2019a). Nearly 66% of their funding is spent on highway and bridge projects for congestion mitigation and reliability improvements, 27% spent on modernization projects, and the remaining spent on expansion and other activities (Massachusetts Department of Transportation, 2018).

3.3.1 Climate

UAS operations are generally sensitive to climate conditions such as precipitation, cold temperatures, windy conditions, etc. Based on available information from 2018, the climate characteristics for Massachusetts are shown in Table 3-4. It can be inferred from this climate data that weather-resistant mitigation measures would bolster the use of UAS technology year-round including purchasing weather-resistant UAS hardware, purchasing/cycling additional batteries to balance battery discharge capacity, and implementing acclimation protocols for hardware (to avoid condensation build up on sensor payloads). Operating UAS at higher altitudes will impact UAS performance and durability.

Table 3-4. Massachusetts climate data for 2018 and elevation data. (National Oceanic and Atmospheric Administration, 2019)

Measure	Data
Average wind speed	8 mph
Average wind gust speed	25 mph
Average maximum 5-second wind gust speed	62 mph
Average annual precipitation	54.36 inches
Average days of precipitation > 0.1 inch	91 days
Average maximum precipitation	3.09 inches
Average minimum temperature	-6° F
Average temperature	51° F

Measure	Data
Annual clear/scattered cloud sky conditions[4]	165 days
Highest/lowest elevation	3,487 feet/ Sea Level

3.3.2 Mission, Vision, and Goals

The mission of MassDOT is to deliver excellent customer service to people traveling in the Commonwealth by providing transportation infrastructure which is safe, reliable, robust and resilient. The agency supports programs and projects that yield a high return on investment. MassDOT supports the economic, quality of life, and environmental goals of the Commonwealth.

3.3.3 Strategic Priorities

The Commonwealth's recently released draft STIP (FFY 2020-2024) and CIP (2020-2024) outlines the reliability investments as its highest priority followed by modernization and expansion. These are investments made to enhance the overall condition and reliability of the transportation assets and it includes projects for routine and capital maintenance, State of Good Repair, asset management and system preservation (Massachusetts Department of Transportation, 2019b).

While the agency does not identify UAV explicity as a game-changer in planning level, it has a chartered UAS program that resides within it's aeronautics division that monitors the operations of UAS in flight services.

3.3.4 Unmanned Aircraft System (UAS) Operations

In October 2017, MassDOT developed an interim drone policy to enable development of legal and standard methods to access drones and provide required support for safe and effective operation of UAS (DeCarlo, 2017). The policy applies broadly to both employees and contractors performing MassDOT work. It ensures commitment to safety, addressing privacy concerns, and policies concerning retention and use of flight data, and cooperation with law enforcement agencies. The policy mandates compliance with all applicable Federal (CFR Part 107) and State regulations (no current State-specific laws exist in the Commonwealth)

MassDOT's Aeronautics Division is conducting an Unmanned Aerial Vehicle Pilot program to examine the use cases of UAS for transportation applications and to facilitate the adoption of drones in a safe and cost-effective manner (Mihaley, 2019).The objective also includes documenting best practices and lessons learned and promoting applied research to support UAS operations and develop counter-UAS missions. The pilot program focused on multiple use cases including Incident response, airport pavement evaluation and construction site monitoring

[4] Day and night. Weather station observation records without sky condition data were retained for chronological integrity. There was no indication why sky condition data was not recorded for some observation times.

3.3.5 UAS Program Structure

MassDOT's UAS program is managed and administered by Aeronautics Division. The Drone Program is overseen by a nine-member Steering committee that meet quarterly and incorporate required changes to the Policy and other governing documents. The agency also has 5-8 employees who possess FAA's Remote Pilot Certification excluding those who are currently enrolled in the UAS program and pursuing the certificate. It performs approximately 90 percent of the UAS work in-house and remaining work completed by consulting services

3.3.6 Implementation Challenges

Initial implementation challenges included establishing a vision for their UAS program given the dynamic regulatory environment and technology advancements.

3.3.7 UAS Program Funding

Currently, MassDOT reported they have a dedicated funding source for the UAS program.

3.3.8 UAS Equipment and Software

MassDOT owns the following fleet of aircraft:

- Five - DJI® Phantom 4
- Two – DJI® Inspire 2
- One each of DJI® Matrice 210, Yuneec H520, SenseFly eBee, Delair UX11

The following software packages are used to support MassDOT UAS operations:

- 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 Autodesk suites – Photogrammetry and image processing
- Other standalone image and video editing software.

3.3.9 UAS Training

MassDOT stipulates adherence to additional training needs as determined by Part 107. Before a member can fly as an PIC, they must complete training and obtain FAA Part 107 certification through an approved testing facility. They must also demonstrate their ability and knowledge of the UAS through sufficient training in operating the aircraft safely and effectively.

Recurrent training requirements are meant to ensure all members within the unit maintain proficiency in their PIC/observer abilities. Recurrent training is not limited to actual operating/observer skills but includes knowledge of all pertinent UAS/aviation matters. Failure to prove proficiency can result in removal from UAS responsibilities.

3.3.10 Transportation Applications and Priorities for Integrating UAS Technology

Some permitted uses include (but are not limited to) photogrammetry/3D modeling, aerial photography, structural inspection, and monitoring traffic and safety operations. The high-priority applications for MassDOT are as follows:

- Construction inspection
- Emergency and incident response during natural and human-caused disaster
- Environmental Assessment
- Slope stability analysis and change detection

3.4 New Hampshire Department of Transportation

NHDOT employs around 1,326 staffs and expended approximately $732 M (FY 2018) in its investment on highway, pavements, and bridges. The agency manages nearly 4,606 Centerline miles of pavements and 2,162 bridges

NH DOT generally relies on funding from several sources including Federal highway trust fund, State sources such as General Fund, Turnpike Fund, General Obligation Bonds, multimodal state funding, grants, and municipal partnerships. Nearly 34% of their funding in the decade from 2009-18 is spent on construction of new projects, 29% spent on Operations budget (that includes adminstration, project development, and Operations and Maintenance costs), and the remaining spent on other activities (such as debt services, Department of Safety etc) (New Hampshire Department of Transportation, 2019).

3.4.1 Climate

UAS operations are generally sensitive to climate conditions such as precipitation, cold temperatures, windy conditions, etc. Based on available information from 2018, the climate characteristics for New Hampshire are shown in Table 3-5. It can be inferred from this climate data that weather-resistant mitigation measures would bolster the use of UAS technology year-round including purchasing weather-resistant UAS hardware, purchasing/cycling additional batteries to balance battery discharge capacity, and implementing acclimation protocols for hardware (to avoid condensation build up on sensor payloads). Operating UAS at higher altitudes will impact UAS performance and durability.

Table 3-5. New Hampshire climate data for 2018 and elevation data. (National Oceanic and Atmospheric Administration, 2019)

Measure	Data
Average wind speed	6 mph
Average wind gust speed	29 mph
Average maximum 5-second wind gust speed	46 mph
Average annual precipitation	47.60 inches
Average days of precipitation > 0.1 inch	93 days
Average maximum precipitation	2.61 inches
Average minimum temperature	-19° F
Average temperature	46° F

Measure	Data
Annual clear/scattered cloud sky conditions[5]	145 days
Highest/lowest elevation	6,288 feet/ Sea Level

3.4.2 Mission, Vision, and Goals

The mission of NHDOT is to achieve transportation excellence enhancing the quality of life in New Hampshire. The strategic goals NHDOT has set forth include the following (New Hampshire Department of Transportation, 2019):

- Increase Customer Satisfaction providing transparent communication and being responsive to the citizens of New Hampshire and users of the systems.
- Improve Performance in all business operations including asset conditions, mobility, system safety and security, department efficiency, and stakeholder engagement.
- Improve Resource Management by effectively managing financial resources, protecting and enhancing the environment, and implementing strategic workforce planning.
- Implement Employee Development strategies that increase bench strength, optimize employee health and safety, and align employees around the department's mission.

3.4.3 Strategic Priorities

The recently released NHDOT's Asset Management Plan outlines the mission to provide efficient tracking and inventory of assets and develop efficient resource management strategies to minimize cost while achieving State of Good Repair. The Long-Range Transportation Plan of the agency also reiterates the agency's commitment towards its goal area of ensuring safety and system preservation and maintenance recognizes that innovation is required to help meet the needs and demands of the transportation system.

While NHDOT have not identified UAV as a key enabler at the planning level, the agency has been developing policy and operational guidelines for enhancing its use for various applications.

3.4.4 Unmanned Aircraft System (UAS) Operations

In New Hampshire DOT, the UAS operations is monitored by Bureau of Aeronautics. However, the agency has not formally planned for or operated its first flight. Most of the policy guidelines and regulations are redirected to Part 107 requirements. The State also requires compliance with 14 CFR 101 and FAA Advisory Circular 91-57A for recreational UAS operations.

The State law, statutes RSA Chapter 422 and Code of Administrative Rules Chapter Tra 900, requires all aircrafts owned by New Hampshire residents and/or businesses must be registered annually with the Bureau of Aeronautics regardless of whether the aircraft is in flyable condition or is based or physically located in New Hampshire.

[5] Day and night. Weather station observation records without sky condition data were retained for chronological integrity. There was no indication why sky condition data was not recorded for some observation times.

3.4.5 UAS Program Structure

The NHDOT does not have a chartered UAS program. The Bureau of Aeronautics handles all the registration requests for residents and businesses willing to operate UAS. The agency reported to have developed an UAS policy that governs the UAV deployment. The agency has requested 1 FTE UAS Specialist (with the approval still in process). Notably, the agency includes the requirements for UAS in any jobs that would require UAS operations. At present, all the UAS services at NHDOT is provided by consultants. The agency has a dedicated on-call contract for UAS services and it has conducted around 5-8 UAS flights in the past one year. On August 2019, the agency had posted a project to develop an UAS program that is currently soliciting proposal from interested consultants.

3.4.6 Implementation Challenges

NHDOT feels garnering the management support towards developing a dedicated UAS program is an important challenge in effective implementation

3.4.7 UAS Program Funding

Currently, NHDOT does not dedicate funding for a UAS program.

3.4.8 UAS Equipment and Software

Currently, NHDOT does not own dedicated fleet of UAS equipment and software

3.4.9 UAS Training

Besides the training required as part of Part 107 requirements, the agency does not have an established training program for UAS.

3.4.10 Transportation Applications and Priorities for Integrating UAS Technology

Some permitted uses include (but are not limited to) photogrammetry/3D modeling, aerial photography, infrastructure inspection, environmental analyses, slope failure analysis, confined space inspections, disaster response, and training exercises. The high-priority applications for NHDOT are as follows:

- Topographic mapping.
- Monitoring traffic and safety operations.
- Other planned applications or applications with perceived value to NHDOT include public outreach and engagement, inspection of confined spaces, environmental assessments, and slope stability along rivers.

3.5 Rhode Island Department of Transportation

Rhode Island DOT employs approximately 700 people and expends or disburses more than $570 million per year to deliver its responsibilities and obligations. The agency has nearly 1,100 centerline miles of roadway and over 1,178 bridges, and five rail stations (Rhode Island Department of Transportation, 2019a).

RIDOT generally relies on funding from several sources including Federal formula funds, GARVEE bonds repaid by federal formula funds, and various other state revenues through gas tax, RICAP Funds, toll revenues and others. Nearly 68% of their funding is spent on bridge captial and highway projects, 32% spent on pavement maintenance and preservation and repair and rehabilitation works (Rhode Island Department of Transportation, 2019b)

3.5.1 Climate

UAS operations are generally sensitive to climate conditions such as precipitation, cold temperatures, windy conditions, etc. Based on available information from 2018, the climate characteristics for Rhode Island are shown in Table 3-6. It can be inferred from this climate data that weather-resistant mitigation measures would bolster the use of UAS technology year-round including purchasing weather-resistant UAS hardware, purchasing/cycling additional batteries to balance battery discharge capacity, and implementing acclimation protocols for hardware (to avoid condensation build up on sensor payloads).

Table 3-6. Rhode Island climate data for 2018 and elevation data. (National Oceanic and Atmospheric Administration, 2019)

Measure	Data
Average wind speed	8 mph
Average wind gust speed	24 mph
Average maximum 5-second wind gust speed	63 mph
Average annual precipitation	59.39 inches
Average days of precipitation > 0.1 inch	92 days
Average maximum precipitation	2.89 inches
Average minimum temperature	-4° F
Average temperature	52° F
Annual clear/scattered cloud sky conditions[6]	167 days
Highest/lowest elevation	812 feet/ Sea Level

3.5.2 Mission, Vision, and Goals

To facilitate the safe and efficient movement of people and goods through Rhode Island, the Department's primary objective is achieving and maintaining a State of Good Repair for its network of roads and bridges. The goals RIDOT has set forth include the following (Rhode Island Department of Transportation, 2019b):

- Achieve and maintain a State of Good Repair
- Improve Public Safety
- Coordinate effectively across divisions and agencies
- Improve Technological Capabilities

[6] Day and night. Weather station observation records without sky condition data were retained for chronological integrity. There was no indication why sky condition data was not recorded for some observation times.

3.5.3 Strategic Priorities

The passage of Rhodeworks, a State law enacted to restructure the agency to address the deteriorating condition of RIDOT's assets, created a paradigm shift in agency's approach to asset management. The $5 Billion program led the agency to develop first-ever transportation plan for the state and provided the needed resources to plan and execute projects that will lead to State of Good Repair by 2025 (Rhode Island Department of Transportation, 2019a).

Consistent with RIDOT's goal of enhancing its state of good repair and technological capabilities and keeping in pace with the Rhodeworks' expectations, RIDOT has acknowledged the importance of UAS technolgy and is developing an implementation program and building support from its management.

3.5.4 Unmanned Aircraft System (UAS) Operations

RIDOT is evolving in terms of developing a UAS Program with its major components. The agency reported to have conducted its first flight in 2016 and has been since then averaging one flight a year. The regular Part 107 UAS regulations apply to the State. According to the Rhode Island General Assembly, the State law [HB 7511 (2016)] grants exclusive authority over UAS operational regulations and policies to the State legislature and Rhode Island Airport Corporation and pre-empts local governments from creating their own laws (UAV Coach, 2019b). The State DOT reportedly has a one FTE dedicated for UAS operations and one FAA Certified Pilot for UAS flights

3.5.5 UAS Program Structure

The RIDOT does not have an established UAS program, training structure or managed fleet of hardware and software.

3.5.6 Implementation Challenges

RIDOT reported that obtaining management support for program scalability and creating necessary information technology infrastructure remains the biggest challenge for implementation.

3.5.7 UAS Program Funding

Currently, RIDOT does not dedicate funding for a UAS program. However, the agency plans to apply for FHWA'S EDC-5 innovation grant in the future

3.5.8 UAS Equipment and Software

Currently, RIDOT does not have its own formal fleets of equipment and software.

3.5.9 UAS Training

Besides the requirements of the FAA, the RIDOT does not mandate any specific UAS training program

3.5.10 Transportation Applications and Priorities for Integrating UAS Technology

RIDOT has reported application of UAS for public outreach and engagement, topographic mapping, and bathymetric surveying as integral to its mission. Other applications perceived of importance to the agency's mission include bridge and structural inspection, construction inspection, emergency and incident response, and environmental assessment

3.6 Vermont Transportation Agency

VTrans' Transportation Programs are worth $611M for FY2019 to deliver its responsibilities and obligations. The Agency has nearly 14,174 lane miles of roadways, over 4050 bridges and culverts, 578 miles of rail lines, 16 public airports (Vermont Agency of Transportation, 2019). The Agency's Highway Department constructs and maintains its highways and bridges . It has 850 staffs and had $492M allocated to meet its obligations in SFY 2019.

VTrans generally relies on funding from several sources including Federal highway trust fund, state bonding, interdeprtmental transfers,and other local sources (Vermont Agency of Transportation, 2019) .

3.6.1 Climate

UAS operations are generally sensitive to climate conditions such as precipitation, cold temperatures, windy conditions, etc. Based on available information from 2018, the climate characteristics for Vermont are shown in Table 3-7. It can be inferred from this climate data that weather-resistant mitigation measures would bolster the use of UAS technology year-round including purchasing weather-resistant UAS hardware, purchasing/cycling additional batteries to balance battery discharge capacity, and implementing acclimation protocols for hardware (to avoid condensation build up on sensor payloads). Operating UAS at higher altitudes will impact UAS performance and durability.

Table 3-7. Vermont climate data for 2018 and elevation data. (National Oceanic and Atmospheric Administration, 2019)

Measure	Data
Average wind speed	5 mph
Average wind gust speed	22 mph
Average maximum 5-second wind gust speed	50 mph
Average annual precipitation	41.87 inches
Average days of precipitation > 0.1 inch	93 days
Average maximum precipitation	1.92 inches
Average minimum temperature	-23° F
Average temperature	45° F
Annual clear/scattered cloud sky conditions[7]	142 days
Highest/lowest elevation	4,393 feet/ 95 feet

[7] Day and night. Weather station observation records without sky condition data were retained for chronological integrity. There was no indication why sky condition data was not recorded for some observation times.

3.6.2 Mission, Vision, and Goals

The mission of VTrans is to provide excellent customer service for the safe and efficient movement of people and goods. The Vision is to provide a safe, reliable, and multimodal transportation system that grows the economy, is affordable to use and operate, and serves vulnerable population. The goals VTrans has set forth include the following:

- Promote organizational excellence by attracting, developing, and retaining a talented, diverse, and engaged workforce.
- Grow Vermont's economy by providing a safe, reliable, and efficient transportation system in a state of good repair.
- Make Vermont more affordable and serve the vulnerable by providing accessible, convenient, and affordable travel choices.
- Transition to an energy efficient, advanced technology transportation system.
- Modernize and improve government efficiency through innovation, continuous improvement, and quality customer service.

3.6.3 Strategic Priorities

The recently released 2040 Long Range Transportation Plan recognized the growth and integration of innovative technologies such as Autonomous Vehicles, 5G cellular networks, and their implications on planning, building and managing the transportation system. It also specifically highlights the positive impact of technological innovation on enhancing the safety and security across all transportation modes, preserving state of good repair of critical assets, and ensuring overall mobility and accessibility (Vermont Agency of Transportation, 2018). The State has an established UAS program to support flight missions that could align well with its strategic long term priorities.

3.6.4 Unmanned Aircraft System (UAS) Operations

Between 2014 and 2016, Vtrans had conducted a major research intiative that studied deployment of UAS for transportation decision-making (O'Neil-Dunne, 2017).The study documented the processes used to deploy UAS for bridge inspections and highlighted it's cost-effectiveness and efficiency in producing variety of data products. Vtrans require compliance with CFR Part 107 regulations for operating UAS to support any of the State transportation work. The State's UAS Program Coordinator reserves the right to deny any proposed UAS flight operation if operational risk exceeds acceptable tolerances or the operation will violate FAA regulations or Department policy. UAS policy, guidelines, procedures, and implementation are reviewed annually.

3.6.5 UAS Program Structure

The agency reports to have an established UAS program under Rail and Aviation Bureau that is comprised of 11 members including a Program Coordinator, FAA certified remote pilots, Vtrans-trained Visual Observers, Airport Operation Specialists, Civil Engineer, and a GIS mapping and data processing specialist (Delabruere, 2019). The agency reported to have started its first formal UAS operation in July 2018 and intends to have steady state operations by Dec. 2020 with its internal feet and contractor support to manage various applications such as emergency response, infrastructure inspection, construction site monitoring, and aerial imagery. The agency performs 90 percent of UAS work in-house and the remaining through consultants. In the past one year, the agency had conducted 100+ UAS flights through its in-house capabilities and consultants. The agency also works with Department of Public Safety in integration of UAS operations.

3.6.6 Implementation Challenges

According to VTrans, procurement of hardware and software and ensuring the department remains flexible to accommodate the needs of an UAS program are the key implementation challenges

3.6.7 UAS Program Funding

VTrans' Rail and Aviation Bureau had received State funds to set up the UAS program. Currently, VTrans had also applied for FHWA's State Transportation Innovative Council (STIC) Grant for supporting the financial requirements of UAS program.

3.6.8 UAS Equipment and Software

VTrans owns a DJI® Phantom 4 (multicopter) with HD Video and a 12 MP camera that is being used for training and current missions. VTrans intends to increase its equipment fleet to 5-7 UAS by 2020

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.

3.6.9 UAS Training

Before a member can fly as an PIC, they must complete training and obtain FAA Part 107 certification through an approved testing facility. They must also demonstrate their ability and knowledge of the UAS through sufficient training in operating the aircraft safely and effectively, as determined by the UAS Program Coordinator.

3.6.10 Transportation Applications and Priorities for Integrating UAS Technology

Some permitted uses include (but are not limited to) photogrammetry/3D modeling, aerial photography, infrastructure inspection, environmental analyses, slope failure analysis, confined space inspections, disaster response, and training exercises. The high-priority applications for VTrans are as follows:

- Bridge maintenance and structural inspection. VTrans research initiative to evaluate UAS for inspection yielded positive results for continued deployment of UAS
- Aerial mapping.
- Emergency/incident response. VTrans is planning for the use of UAS technology in support of their emergency response activities (natural and human-caused).

- Other planned applications or applications with perceived value to VTrans include public outreach and engagement, inspection of confined spaces, environmental assessments, and slope stability along rivers.

4.0 TRANSPORTATION APPLICATIONS

State DOTs have shown increased interest in utilizing UAS for various transportation applications over the past decade. Recognizing the potential benefits, many state DOTs have explored implementation of UAS through pilot projects and several of them have developed operation manuals and policies to support systematic use of UAS in their transportation projects. Currently, the more popular use cases for integrating UAS technology for transportation activities include monitoring traffic, structural inspection, construction progress monitoring and inspection, crash scenes reconstruction, emergency response/recovery, public outreach and engagement.

Research by Kansas State University in 2016 noted several applications that would benefit from the use of UAS technology (shown in Table 4-1). While the regulatory (before Part 107 enacted) and technological fabrics have advanced since this was published, it provides a benchmark of key considerations to be evaluated.

Table 4-1. Summary of UAS Applications. (McGuire, Rhys, & Rhys, 2016)

KDOT Tasks	UAS Application	Cost Savings	Safety Enhancement	Increased Efficiencies	Challenges
Bridge Inspection	Yes	TBD	Yes	Yes	Learning new software, changing roles, regulation of not flying above people not involved in operation.
Radio Tower Inspection	Yes	TBD	Yes	Yes	Learning new software, changing roles, battery life, and flight time ability.
Surveying	Yes	TBD	Yes	Yes	Learning new software, changing roles, battery life and flight time of UAS can't provide continuous data collection, regulation of not flying above people not involved in operation.
Road Mapping	Yes	TBD	Yes	Yes	Can only use photogrammetry in November-April (less vegetation), regulation of not flying above people not involved in operation.
High-Mast Light Tower Inspection	Yes	TBD	Yes	Yes	Learning new software, changing roles, flight time ability, regulation of not flying above people not involved in operation.

KDOT Tasks	UAS Application	Cost Savings	Safety Enhancement	Increased Efficiencies	Challenges
Stockpile Measurement	Yes	No	No	No	Learning new software, changing roles, regulation of not flying above people not involved in operation.
Photography and Videography	Yes	No	No	No	Regulation of not flying above people not involved in operation.
Railroad Intersections Inventory	No	No	No	No	Flight time ability, and regulation of not flying above people not involved in operation
Traffic Data Collection	No	No	No	No	Battery life and flight time of UAS can't provide collection.

Expanding on this initial research by Kansas State University, additional literature and interviews found that the use of UAS for certain transportation applications has evolved and is a general improvement to traditional methods. This improvement is manifested in different areas for each application such as decreasing field time, improving data analytics and sharing, and improving safety by limiting exposure to risks. A detailed review and analysis on these applications can be found in subsequent sections. Table 4-2 provides a summary of this analysis on the efficacy of each application.

Table 4-2. Summary of analysis on the efficacy of using UAS compared with traditional methods of performing each application.

Transportation Application	Effectiveness in achieving objectives	Efficiency in performing required tasks	Safety improvements	Cost/Labor Savings
Traffic Monitoring	High	Low	Medium	Medium
Structural Inspection	High	Medium	High	Medium
Construction Inspection	High	Medium	Medium	Medium
Surveying and Mapping	Medium	Medium	High	Medium
Environmental Assessment	Medium	Medium	High	Medium
Emergency and Incident Response/Recovery	High	Medium	High	Medium
Public Outreach and Engagement	High	Medium	Low	Medium

While adoption of UAS technology would require some key changes to the technological and informational processes governing each application, there are opportunities for enabling systematic integration of UAS with the traditional methods to enhance the utility of the final product. The opportunity to replace major traditional workflow elements by introducing UAS technology is limited and was not supported by evidence. This section discusses the high-potential transportation applications ripe for UAS integration with traditional methods.

4.1 Monitoring traffic and safety operations

4.1.1 Traditional Methods

Monitoring traffic to support effective traffic management and control operations remains one of the key objectives for many state DOTs and emergency responders. Highways experiencing traffic congestion from an imbalance of facility capacity and demand or because of emergency incidents causing gridlocks, which often lead to significant economic impact for drivers and businesses. There are many technologies to monitor traffic and collect real-time traffic data to including closed-circuit television cameras, loop sensors, radar detectors, and other tools. State DOTs also resort to active traffic management strategies such as ramp metering, variable speed limit, traffic signal control, dynamic lane reversal, queue warning, etc. (Federal Highway Administration, 2019b). Most of these strategies often require accurate information on field conditions to work efficiently.

FHWA developed a traffic monitoring guide that describes two methodologies for traffic counting including continuous and short duration. Continuous count stations collect data 24 hours each day over the entire year and can be used to develop adjustment factors, track traffic volume trends on important roadway segments, and provide inputs to traffic management and traveler information systems. Short duration count stations focus on collecting data for 24 hours each day up to a few weeks. (Federal Highway Administration, 2016). Using UAS technology strictly for traffic counts is not suitable given the limitations with flight duration and visual line of sight requirements. (Federal Highway Administration, 2016b)

4.1.2 UAS Integration Opportunities

Operating UAS for traffic monitoring can largely be performed under Part 107 requirements without a need to secure any waivers. Some waivers to Part 107 that could potentially be required or obtained to improve use of UAS for traffic monitoring include operating a UAS at night (Part 107.29), beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), operating over people (Part 107.39), and operating outside speed, altitude, and visibility thresholds (Part 107.51). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. UAS can effectively monitor intersections and small areas within range of the sensor payload, but are limited in monitoring larger areas and in areas where airspace access is restrictive.

Small UAS can prove to be a flexible tool for traffic monitoring applications with its ability to quickly collect the data required for further analysis and decision-making support. UAS can be conveniently (or strategically) positioned at various intersections to monitor traffic especially during traffic hours (see Figure 4-1). UAS can be used to monitor congestion and collect information on traffic flow to augment the operational efficiencies of other sensor technologies and enhance the performance of various active traffic management technologies. This data can be processed and used for improved decision making and provide valuable information for commuters.

Figure 4-1. Photo. Traffic monitoring of an intersection using a UAS.

Several instances exist in the literature where UAS had been piloted to study traffic operations monitoring and the associated policy implications.

- USDOT and NASA sponsored a research program for an unmanned Airborne Data Acquisition System (ADAS) for traffic surveillance, monitoring and traffic management. The ADAS developed had a maximum flight time of 2 hours and could carry payloads up to 20 punds, and had nine interchangeable sensor platforms. The ADAS platform is capable of flying under a combination of pre-programmed Differential Global Positioning Satellite (DGPS)-based navigation and manual direct ground control. ADAS was fully tested and was planned for use in several US Department of Defense base-monitoring studies that year (Carroll & Rathbone, 2008). Virginia DOT had implemented ADAS to do real time traffic surveillance and monitor incidents.
- The Georgia DOT in collaboration with Georgia Technological University commissioned a $75,000 pilot study to test the potential for drones for uses related to traffic management and found UAS technology can be used for congestion monitoring, traffic signal inspection, and vehicle speed sampling (Roads&Bridges, 2014).
- The Michigan DOT, in collaboration with Western Michigan University, deployed UAS for traffic monitoring and emergency response to design a transmission system for sending live images to traffic management agencies for enabling expedited decision-making. They deployed a BAT III platform from the MLB company. The communication system of the technology is shown below (Kamga, Sapphire, Moghimidarzi, & Khryashchev, 2017).

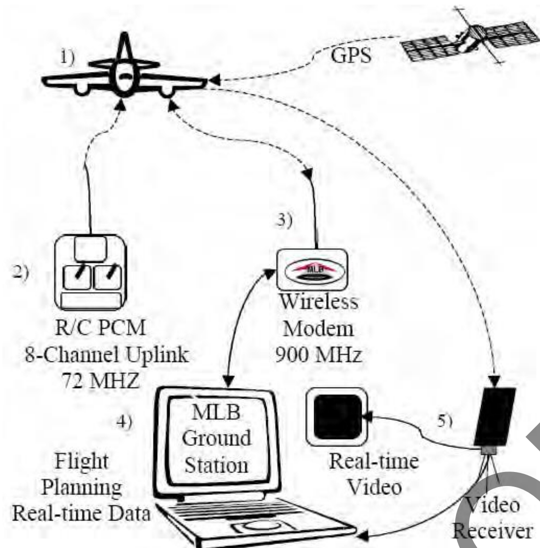


Figure 4-2. Illustration. UAS communication system.

- Many state DOTs and universities are also deploying UAS for traffic data collection (counting) using DataFromSky, a video analytics platform that leverages the capabilities of machine learning and Artificial Intelligence to automatically extract traffic data from cameras and process it to obtain valuable information. This platform can provide traffic counts, vehicle flows, vehicle classification, gap time, follow-time and Origin-destination information. Examples of origin/destination data and travel speed information are shown below (DataFromSky, 2019)

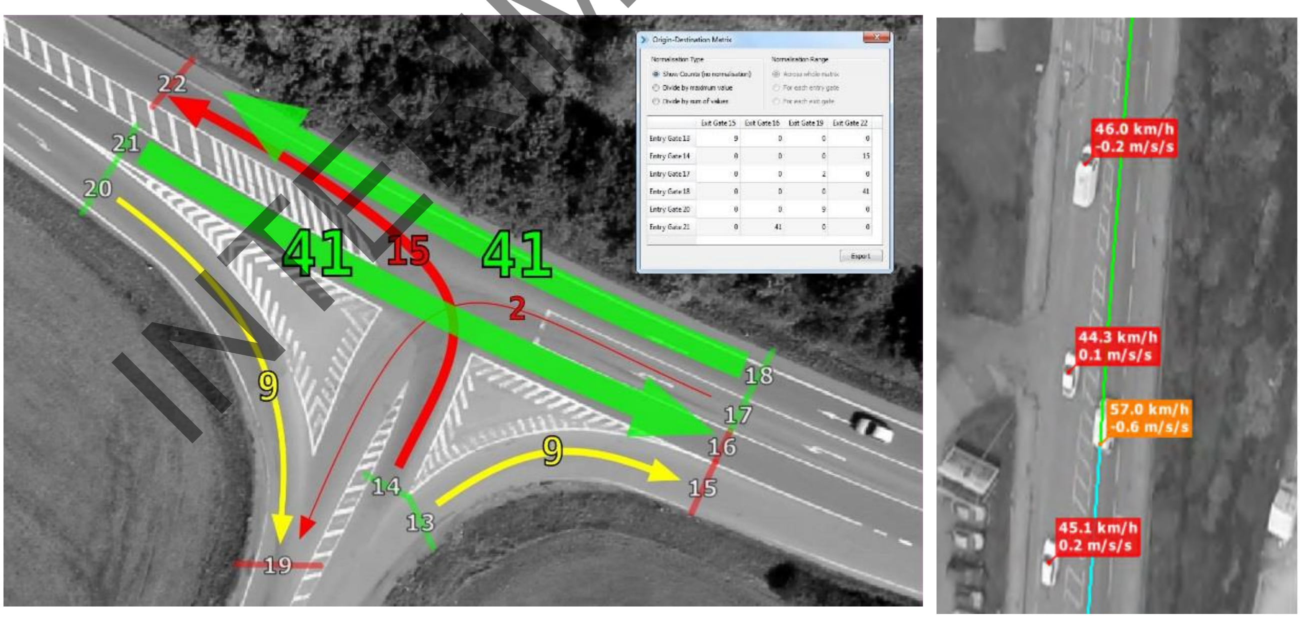


Figure 4-3. Photo. UAS data sets for traffic monitoring.

4.1.3 Benefit/Cost Information

Monitoring traffic conditions through UAS provides state DOTs with flexible, cost-effective solutions to collect useful traffic data and respond to incidents or emergency situations. (Carroll & Rathbone, (2008) estimated that the potential return on investment for an agency that had invested in aerial data collection and traffic monitoring is significant. Using the FHWA information on a reported average amount of funds spent annually for traffic data collection for a typical metropolitan area with a population of over 200,000 and factoring in the associated staff budget, it was calculated that state DOTs in an average metropolitan area spend approximately $5 million per year in traffic data collection. The manual data collection can be replaced by ADAS in about half of the data collection instances, thereby leading a cost-reduction of 20% (Carroll & Rathbone, 2008).

4.1.4 Assessment

Table 4-3. Efficacy of using UAS for monitoring traffic and safety operations. Sources:

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	Small UAS can be deployed for traffic monitoring and management; the utility of the tool can increase if combined with other sensor technologies such as loop detectors, UAS tethers, etc.	Deployment of UAS over crowded traffic corridors could have potential legal and safety implications. It can also be impacted by adverse weather conditions.
Efficiency in performing required tasks.	Low	The resulting video stream from UAS can be processed using artificial intelligence and deep learning to extract significant traffic data including vehicle speeds, gap time, origin-destination information, etc.	Suboptimal weather conditions inhibit flights and could delay operations. Mobile connectivity to ground control station is critical towards enabling real-time decisions and may be elusive in rural areas. Duration of each flight is also a limitation: typical flight durations are less than one hour. Simple traffic counting (continuous and short duration) is not suitable for using UAS.
Safety improvements	Medium	Use of UAS for traffic management helps operators and first responders by providing live-video streams and enables them to respond more effectively. It also reduces the man-hours spent	Presence of UAS over congested traffic corridors can cause distractions to vehicular drivers thereby creating potential safety hazards.

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
		in the field thereby increasing the safety of the commuters and agency staffs.	
Cost/Labor Savings	Medium	Cost savings due to labor hours spent on data collection and safety improvements for commuters and field personnel.	Potential higher cost for data processing of video-stream, especially to use the information for real-time traffic management and incident response.

4.2 Structural Inspection

4.2.1 Traditional Methods

State DOTs follow National Bridge Inventory Standards (NBIS) for inspecting and assessing a variety of in-service bridges. Bridge inspection plays a key role in ensuring public safety and confidence in bridge structural capacity and integrity to effectively perform maintenance and rehabilitation operations. Legislatively, bridge inspection needs to comply with federal standards to receive federal funding for bridge rehabilitation and replacement. State DOTs In order to receive federal funding for bridge maintenance, rehabilitation, or replacement, bridge inspection processes/methods need to comply with federal standards. Also, state DOTs establish more detailed guidelines for short-term periodic inspections including hands-on bridge inspection processes, close-up reviews, and collecting quantitative bridge data. The basis of these guidelines is the condition of bridges in the state, their defects, and local postings. Some states develop their customized inspection procedures that goes beyond the minimum requirements promulgated by FHWA.

As described in the Bridge Inspector's Reference Manual, conventional procedures for routine bridge inspection follows evaluating conditions of various elements of a bridge, calculating the rating of the bridge, and recording them in the inspection report for state DOTs/asset owners, which ultimately gets submitted to the National Bridge Inventory (Federal Highway Administration, 2012). Special safety precautions need to be taken for ensuring safety of the personnel involved through temporary traffic control and ensuring various access control measures. Inspectors often use variety of equipment for data collection depending on the type of the bridge and the nature of the inspection (routine/fracture critical/underwater). These tools include:

- Tools for Cleaning
- Tools for Inspection
- Tools for Visual Aid
- Tools for Measuring
- Rotary Percussion
- Scour Monitoring Collar
- Scour Monitoring Collar Schematic
- Remote Camera

- High Speed Underclearance Measurement System
- Tablet PC Used to collect inspection data

The Bridge Inspector's Reference Manual also mentions recent developments in equipment that includes deployment of remote cameras and laser scanners for data collection and recording. Remote cameras can be used to collect spatial information and conduct surface analysis that can distinctly identify the flaw/defect in surface using its size, shape, location, and other attributes. Laser scanners collect point cloud data that can be used to construct 3D as-builts providing realistic representation of the facility and assist field inspection such as targeting discrete areas of concern.

4.2.2 UAS Integration Opportunities

Operating UAS for structural inspection can largely be performed under Part 107 requirements without a need to secure any waivers. Some waivers to Part 107 that could potentially be required or obtained to improve use of UAS for structural inspection include operating a UAS at night (Part 107.29), beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), operating over people (Part 107.39), and operating outside speed, altitude, and visibility thresholds (Part 107.51). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. The UAS can effectively support structural inspection workflows, but there are concerns about data resolution and quality, especially when dust is agitated by downdrafts from propellers. Pairing structural inspection experts with UAS technology is an opportunity to ensure the data being captured supports their decision support construct. UAS technology is likely an enhancement to the inspection process (i.e. identifying areas for more focused inspection) and not a replacement for visual inspection.

Literature identifies several initiatives where state DOTs have utilized UAS for carrying our structural bridge inspections. Oregon DOT conducted UAS flights for inspecting four bridges as part of a research project. These inspections validated the utility of the UAS for visual and routine bridge inspections while acknowledging the technology's limitations for fracture-critical inspection that requires "arm's length". With the installation of appropriate sensors and control technology, UAS can often perform efficiently and produce high-resolution imagery at various angles helping in identifying the defects of bridge elements. (Mallela, et al., In Press.)

A UAS can also be effectively deployed to collect data through a variety of sensors especially during routine inspections and in areas where there are severe accessibility constraints. State DOTs have used UAS flights to replace human operations when risk assessment showed that the flights equipped with proper sensors can work with greater productivity and safety than workers using suspended ropes. Alaska Center for Unmanned Aerial System Integration (ACUASI) built a hexacopter equipped with Sony NEX-7 and GoPro camera to conduct inspection of the 280ft long Place River Bridge that had accessibility only through a railroad and required inspectors to climb up and rappel under the structure (Banks et al., 2018). In this project, UAS minimized the time spent on site and increased safety by obviating potentially dangerous situations. The table below summarizes the results of the data acquisition mission.

Table 4-4. Summary of data acquisition mission.

Data Type	Sensor Type	Number of Images/Scans	Data Size (GB)	Comments
Images	Nikon® D800E Sony® Alpha NEX-7	2222 2626	34.9 24.7	Ground-based imagery UAS-based imagery
Video	GoPro®	10	7.57	-
Laser Scanning	FARO® Focus	24	4.26	-
3D Point Cloud	-	5	13.71	-

A research team from Carnegie Melon University and Northeastern University developed the Aerial Robotic Infrastructure Analyst (ARIA), a table-sized drone that uses image cameras and laser scanners to create high-resolution model of bridges. Also, MnDOT has been working on a three-phase research project that aims at demonstrating and standardizing use of drones for selected bridge inspection. The research phases focused on rules and regulations, drone hardware, and ability of drones to collect quality inspection data and enable a workflow to transform the data into actionable inspection deliverables. The pilot inspection was carried out for 17 bridges. Various alternatives for UAS hardware was used including mapping and photogrammetry UAS (SenseFly Albris), commercial inspection drones (senseFly albris, Intel Falcon 8+, DJI M200 Series), consumer grade drones, and a Collision-tolerant UAS (Elios UAS) that was used to access areas that had safety concerns and prohibitive for a large-mapping UAS. The resulting data was processed in several software applications such as Pix4D, ContextCapture, Recap, Intel Insight, and Propeller to produce digital surface models, ortho-imageries, and 3D Point clouds. (Lovelace, 2018)

While MnDOT observed successful testing of UAS in routine inspection of many bridges, there was an instance in Minneapolis, Minnesota where deployment was unsuccessful. It was reported that when UAS flew under bridge superstructure (e.g. girders, etc.) the drafts from propellers agitated the dust and debris, which obscured sensors and diminishes quality of data. Also, some sensors could not identify/locate marks made by bridge inspectors identifying deficiencies (cracks, etc.), the deficiencies were demarcated prior to UAS flight by inspectors using rope access. As a proof of concept, the UAS was deployed to locate these marks, but was not successful. (Lovelace, 2018)

Besides meeting the regular structural inspection requirements, the popularity of the UAS is also on the rise for collecting asset inventory data. The asset management team at state DOTs stands to benefit considerably by deploying drones for tracking locations and conditions of various highway assets including traffic signs, signal heads, guardrails etc. Reconciling the asset data along with characteristics of an asset management system helps produce a more accurate asset inventory, enables compliance checks with various operational requirements, and helps define appropriate maintenance schedules.

Using drones for mapping assets reduces the cost of traffic disruption, decreases the cost of expensive equipment and labor spent on survey time in the field, and improves overall safety and efficiency of asset tracking. Figure 4-4 below shows the 3D mapping of a highway collected using a senseFly eBee Plus RTK drone with the mission planned using eMotion planning software. Utilizing an UAS for mapping this highway helped the team overcome challenging topographic conditions and meet the accuracy requirements.

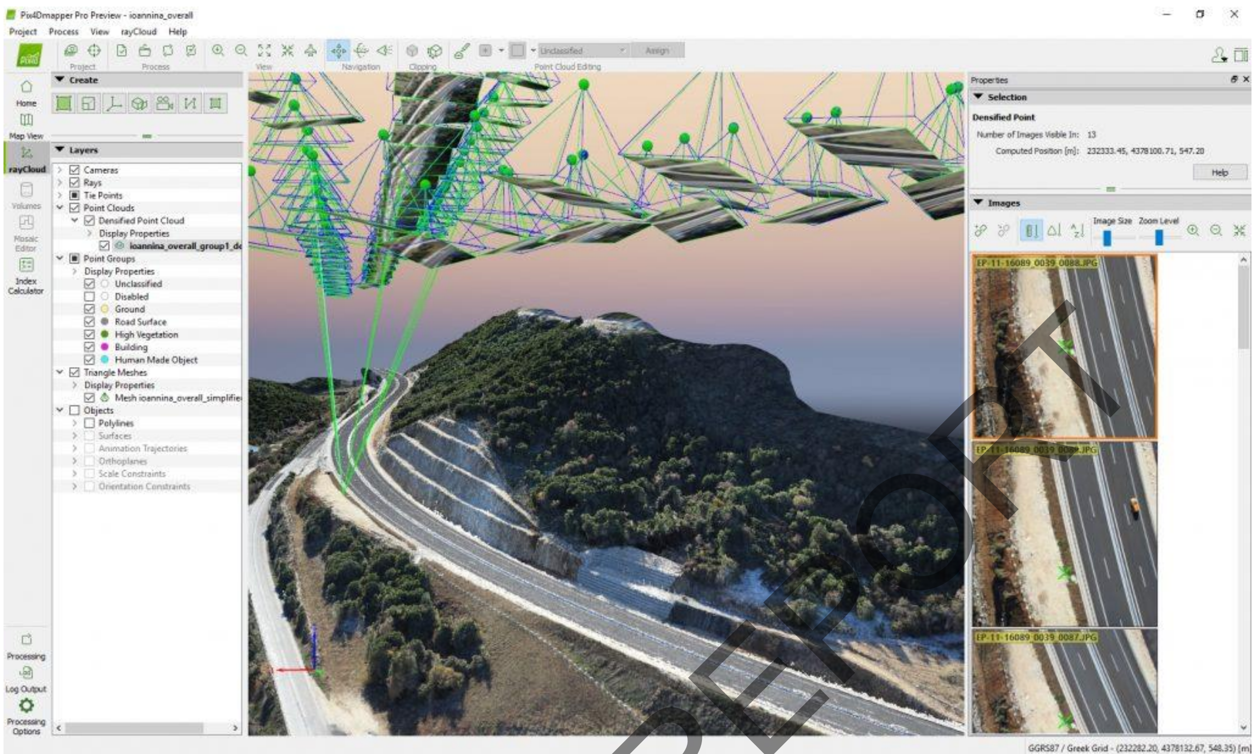


Figure 4-4. Screenshot. Highway mapping using Pix4Dmapper.

4.2.3 Benefit/Cost Information

Oregon DOT reported the main benefits as an average $10,200 per project in the following categories

- Savings in traffic control ($3,500).
- Savings in Equipment rentals such as cranes ($2800).
- Savings in personnel time for travel, lodging, data collection, and potential incidents ($3,900).

The major costs included the UAS cost (SenseFly Albris UAS), travel costs for any additional pilot/Visual observer per project (if some existing personnel in the team is not trained) and marginal increase in office time for image/video processing. The analysis of the data revealed that the breakeven for investing in this technology occurs quickly (Banks et al., 2018) .

MnDOT findings through the research program also included detailed evaluation of savings in cost between UAS assisted and traditional inspections and the variation in man-hours as shown in Figure 4-5 (Lovelace, 2018)

Structure	Traditional Inspection Cost	UAS Assisted Inspection Cost	Savings +/-	Savings Percentage	Traditional Inspection Hours	UAS Assisted Inspection Hours	Savings +/-
19538	$1,080	$1,860	-$780	-72%	8	12	-4
4175	$15,980	$13,160	$2,820	18%	48	48	0
27004	$6,080	$4,340	$1,740	29%	8	16	-8
27201	$2,160	$1,620	$540	25%	16	10	6
MDTA Bridges	$40,800	$19,800	$21,000	51%	80	120	-40
2440	$2,160	$1,320	$840	39%	16	10	6
27831	$2,580	$540	$2,040	79%	8	3	5
82045	$2,660	$1,920	$740	28%	16	12	4
62080	$2,580	$1,350	$1,230	48%	8	8	0
62090	$2,410	$1,570	$840	35%	16	10	6
62504	$3,660	$1,020	$2,640	72%	16	8	8
82502	$3,240	$2,400	$840	26%	24	16	8
			Average Cost Savings	40%		Average Hours Increase	2%

Source: Minnesota Department of Transportation

Figure 4-5. Illustration. Inspection Costs and Manhours for Traditional and UAS assisted inspections. (Lovelace, 2018)

The Delaware River and Bay Authority (DRBA) used a UAS Pilot Program to collect imagery of various features of Delaware Memorial Bridges including anchorages, concrete piers, towers, cables, suspender ropes, approach steel superstructure and high mast light towers (Sullivan, 2017). The Program estimated the following benefits in comparison to a Rope Access Program. The assumptions included:

- Rope Access field crew consists of 3 inspectors/technicians; Drone field crew consists of 2 inspectors/technicians; plus $500 equipment cost.
- Rope access field production rate = 1 pier per day; 4 suspender ropes per day; Drone field production rate = 4 piers per day; 12 suspender ropes per day.
- Rope Access office work includes 1 inspector to re-sketch (clean-up) field notes; Drone office work includes 1 inspector to post-process images/video and trace defects onto CAD sketch.

Cost Comparison of
Industrial Rope Access vs. Unmanned Aircraft Systems (Drones)

Concrete Pier Inspection

	Field Work			Office Work			
Inspection Method	Time Required (days)	Unit Cost (day)	Field Cost	Time Required (days)	Unit Cost (day)	Office Cost	**Total Cost**
Rope Access (one pier)	1	$3,000	$3,000	0.5	$1,000	$500	**$3,500**
Drone (one pier)	0.25	$2,500	$625	1.5	$1,000	$1,500	**$2,125**
Total Cost To Inspect All Large Piers							
Drone	3	$2,500	$7,500	4.5	$1,000	$4,500	**$12,000**
Rope Access	7	$3,000	$21,000	3	$1,000	$3,000	**$24,000**
						Total Savings =	**$12,000**

Suspender Rope Inspection

	Field Work			Office Work			
Inspection Method	Time Required (days)	Unit Cost (day)	Field Cost	Time Required (days)	Unit Cost (day)	Office Cost	**Total Cost**
Rope Access (12 Ropes Inspected)	3	$3,000	$9,000	0.5	$1,000	$500	**$9,500**
Drone (12 Ropes Inspected)	1	$2,500	$2,500	2	$1,000	$2,000	**$4,500**
Total Cost To Inspect All Ropes							
Drone	4	$2,500	$10,000	8	$1,000	$8,000	**$18,000**
Rope Access	24	$3,000	$72,000	4	$1,000	$4,000	**$76,000**
						Total Savings =	**$58,000**

Note: Costs do not include any potential access costs such as traffic control or equipment/boats.

Figure 4-6. Illustration. DRBA UAS Program Cost-Benefit Assessment. (Sullivan, 2017)

Michigan DOT has compared the cost savings of deploying an UAS to support inspection of a 4-lane divided highway bridge in metro area to the traditional manual inspection process that involved heavy equipment. It was reported that the manual inspection costed around $4,600 with a 2-person crew and necessary equipment for 8 hours while a 2-person crew using drone had effectively completed similar process in one hour at a cost of $1200, resulting in 74% savings (American Association of State Highway and Transportation Officials, 2019).

4.2.4 Assessment

UAS technology is widely used for structural inspection and has proven to be a versatile tool that delivers value to the inspection process for non-fracture critical components. The following table illustrates an assessment of the efficacy of UAS technology for structural inspection applications.

Table 4-5. Efficacy of using UAS for inspection. Sources: MnDOT (2018), DRBA UAS Pilot Study Program (2018), UAS Research Program (2017), and Michigan DOT (2018).

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	Performing a structural inspection strictly from UAS data is not recommended.	Fracture critical inspection requires arms-length inspection, which precludes

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
		However, pairing UAS technology with traditional methods allows inspectors to achieve the objective.	the use of UAS. There are regulatory constraints that limit the use of UAS to with line of sight, unless a waiver is granted.
Efficiency in performing required tasks.	Medium	UAS technology can be deployed quickly and gather massive amounts of high-resolution imagery and video in a short period. Collecting the data is much quicker that traditional methods using rope access or snooper trucks.	The battery life is a limiting factor in performing inspections. The larger the structure, the more flights are required. Suboptimal weather conditions inhibit flights and could delay operations.
Safety improvements	High	The use of UAS technology can limit time spent climbing on the structure or implementing traffic control. Collecting the data from a safe vantage location without the need for traffic control is beneficial.	The presence of UAS flying around structures has the potential to distract drivers and cause incidents. Also, the risks of injury from a UAS impact are a consideration even for the most seasoned remote pilots.
Cost/Labor Savings	Medium	The use of UAS for structural inspection saves on overall costs for the inspection effort.	There is increased data processing time to analyze the imagery/video and derive actionable insight.

4.3 Construction Inspection

Construction engineering and inspection services can widely benefit from adoption of UAS technologies specifically for tasks such as progress monitoring, quantity measurements, safety monitoring and quality control assessment processes. While the application is not as mature as traditional methods of monitoring construction sites, it is being actively researched upon as an innovative alternative and supplement that can facilitate rapid data collection and at scale.

4.3.1 Traditional Methods

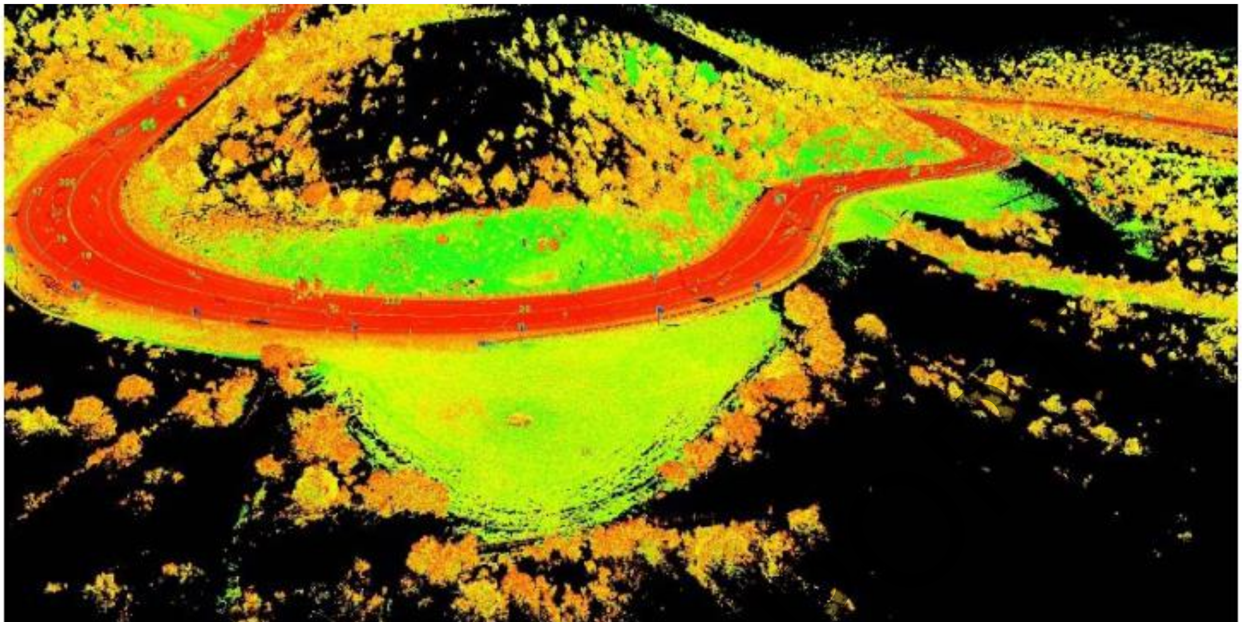
The standard methods of construction review and inspection involves getting acquainted with the project underway through review of pertinent documents before performing the required field activities. The field activities to collect verification data depends on the required granularity of detail about each of the construction elements. Both photographs and sketches are typically recommended to record progress in adequate level of detail to support quality checks against specifications and verifying pay quantities. Inspection reports are then generated and submitted to the appropriate personnel in the project (e.g. quality assurance manager, project manager etc.) to determine further course of action including payments, change orders, claims, or corrective actions.

4.3.2 UAS Integration Opportunities

Operating UAS for construction inspection can largely be performed under Part 107 requirements without a need to secure any waivers. Some waivers to Part 107 that could potentially be required or obtained to improve use of UAS for construction inspection include operating a UAS at night (Part 107.29), beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), operating over people (Part 107.39), and operating outside speed, altitude, and visibility thresholds (Part 107.51). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. The UAS can effectively support construction inspection, but there are considerations for developing training requirements for inspection staff and implementing protocols for using UAS technology to verify certain contractor placement activities. Providing access to UAS technology is likely the key component for integrating UAS into construction inspection workflows, not necessarily equipping inspectors with the technology.

UAS technology with high-resolution video cameras and laser scanners can augment the data collection to assist some of the tasks performed as part of site inspection and progress mentoring. The technique can supplement the needs of data collection specifically on large construction sites with numerous construction activities with limitations of coverage with just using conventional inspection methods. The data collected can also be used to compare reliability and accuracy of the estimates produced using the traditional methods.

Several state DOTs and researchers have attempted to integrate the UAS technology with the workflow for measuring quantities, monitoring construction progress, and performing safety verification opportunities. Many of these studies reported both qualitative and quantitative benefits that have been recorded in the literature. UAS is often used for estimation of earthwork quantities through low-altitude photogrammetry (or photogrammetry-based structure from motion (SfM). It is not uncommon to fuse the UAS data with data from other surveying sources (esp. Static Lidar or MTLS) to enhance the details in the resulting model. Utah DOT has deployed UAS for assisting inspection and estimation of quantities on multiple projects. The agency deployed SenseFly eBee Plus fixed-wing UAS that has a camera to achieve 2.9cm/pixel ground-sampling distance flying at 400 ft. AGL. The resulting data was processed using Pix4D (Mallela, et al., In Press.). They had also produced final as-builts which provides detailed roadway surface (Figure 4-7)



Source: Utah Department of Transportation

Figure 4-7. Image. Utah DOT's As-built point cloud model for SR-20. (Mallela, et al., In Press.)

Oregon DOT has followed similar approach for quantity estimation and payment of quantities. Common areas of integration include measuring earthwork, stockpile volumes, and general area (e.g. clearing and grubbing) and linear-type pay items. It was noted in one of their pilot efforts that using UAS to measure quantities is more suitable for smaller segments of roadway constructed under visual line of sight whereas larger segments often require other supplemental technologies such as traditional GNSS surveys or lidar.

The use of UAS for active construction progress monitoring is also increasingly tested across many highway projects primarily because of the ability to obtain large quantity of data very quickly. The imagery captured can be often used for public outreach (time-lapse videos of construction progress). If the UAS has sensors installed to create point clouds, it is possible to compare as-planned 3D model to determine the progress of various construction element.

NCDOT had utilized UAS for construction inspections and progress monitoring through its research program for a construction site (Snyder, Zajkowski, & Divakaran, 2016). In partnership with NextGen Air Transportation Program (NGAT) at North Carolina State University, the agency conducted a 30-min flight operation to collect orthomosaic image and a DSM of a 150-acre construction site. The key details of the flight operation are shown in Figure 4-8. The digital model of the site was used for monitoring construction progress, volumetric analysis, and establishing strategies and lessons learned to increase UAS use in construction workflows.

Total Hours	Flight Time	30 mins
	Pre & Post Flight Setup	30 mins
	Processing Time	7-8hrs
Conditions	Weather	Good, Light Winds
	Ground	Construction area, Sand, Trees, Initial roads
Type of Data	Sensor	Sony NX30
	Pre-processing	JPG, JXL, CSV, GWT
	Post-processing	TIFF, JPG, XYZ (point cloud), KMZ
Software	Flight Control	Trimble Access Aerial Imaging Software
	Data Processing	Trimble Business Center, Agisoft, Arcmap, ERDAS Imagine

Source: North Carolina Department of Transportation

Figure 4-8. Illustration. NCDOT UAS Program Summary for Construction Site. (Snyder et al., 2016)

The use of UAS for enhancing safety on construction jobsites and avoiding fatalities and injuries is also being investigated. A quadcopter UAS was used to provide real-time visual access to construction jobsites using a large-size interface one tablet devoice. Key components for such a system included autonomous navigation, vocal interaction, high-resolution cameras, and collaborative user-interface environment. (Gheisari, Irizarry, & Walker, 2014)

4.3.3 Benefit/Cost Information

UAS can fly lower than traditional aircraft and achieve the same, if not better, quality data at lower cost for small to medium size surveys. UDOT utilized a combination of UAS and GNSS rovers for collecting digital data during construction on their SR-20 project and observed qualitative improvements in daily reports, visualization for public information, and the overall data collection process. The efficiency improvements in construction inspector's tasks were quantified including efficiencies in labor productivity using labor savings in average time spent by field staffs collecting the information from the field through the project duration and savings in processing time due to automated photogrammetric process. The costs included purchasing the software, hardware, annual maintenance staffs, and full-time equivalent staff to process the data. It resulted in an estimated 2.58% savings in the pilot project contract amount (totaling to $82k) and a 28% return on investment over a period of five years for the annual construction program (Mallela, et al., In Press.).

4.3.4 Assessment

There is increased interest in using UAS technology for construction inspection applications such as quantity measurement/verification and monitoring construction progress. The following table illustrates an assessment of the efficacy of UAS technology for construction inspection applications.

Table 4-6. Efficacy of using UAS for construction inspection. Sources: Federal Highway Administration (2017), Snyder (2016), and Gheisari et al. (2014))

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	High-resolution video cameras and sensors used in traditional methods can be paired with an UAS to achieve similar objectives for construction inspection.	Suboptimal weather conditions inhibit flights and could delay operations. Sensor occlusion is possible in limiting its effectiveness to capture construction elements.
Efficiency in performing required tasks.	Medium	The UAS technology provides rapid assessment of earthwork and stockpile quantities, helps monitor progress on large jobsites in a safe, cost-effective manner.	The technology may require augmentation with other tools when used for payments and measurement of volumes for key elements (such as layers of pavements).
Safety improvements	Medium	Use of UAS for construction inspection can help identify potential safety hazards in jobsites and reduce chances of injury rates by reducing manhours.	The presence of UAS flying around jobsites has the potential to distract workers and cause incidents.
Cost/Labor Savings	Medium	Labor savings due to less manhours spent in collecting g large sample of site data.	Processing time in the office may be higher and labors and personnel may have to be trained.

4.4 Surveying and Mapping

The use of UAS for surveying and mapping is also increasingly becoming a common application for transportation projects. While it is not the preferred method for creating accurate basemaps for engineering design or estimates of quantities, the technology produces a quick scan of the project site to enable the development of 3D mapping products. As the sensors evolve and become cost-effective with increased resolution and accuracy, the technology is likely to become widespread in supporting conventional methods to achieve required objectives.

4.4.1 Traditional Methods

While surveying techniques have evolved over past few decades, surveyors typically use a variety of electronic distance measurement (EDM) devices to measure distances and angles in GNSS-denied areas. Some of the commonly used approaches for surveying include electronic levels, total stations, aerial photogrammetry, remote sensing, laser scanners, and RTK GNSS surveys, among others. They rely predominantly on propagation of light waves or radio waves for direct measurement of distances and angular measurements.

The total station and GNSS are the most pervasive surveying instruments in use throughout the industry to conduct field surveying on many transportation projects irrespective of the scale and complexity. They are light-weight, compact, and fully integrated electronic instruments that can collect positional information on discrete field points and store data as an electronic log book for transmittal and further processing. Robotic total stations (RTS) are also popular given the ability to be remotely controlled requiring only one operator to conduct surveying and inspection operations (Crumal, 2017). Photogrammetry involves combining images taken over an aerial survey to produce 2D or 3D terrain models that is often used to create preliminary estimate of quantities for project developments. In remote sensing, satellite or aircraft-based sensor technologies are deployed to collect and classify information about objects on Earth. Aerial photogrammetry and remote sensing help in collecting vast amount of data about project sites quickly; however, the accuracy of the quantities often require augmentation with other techniques if used for estimation of quantities for bidding and payment

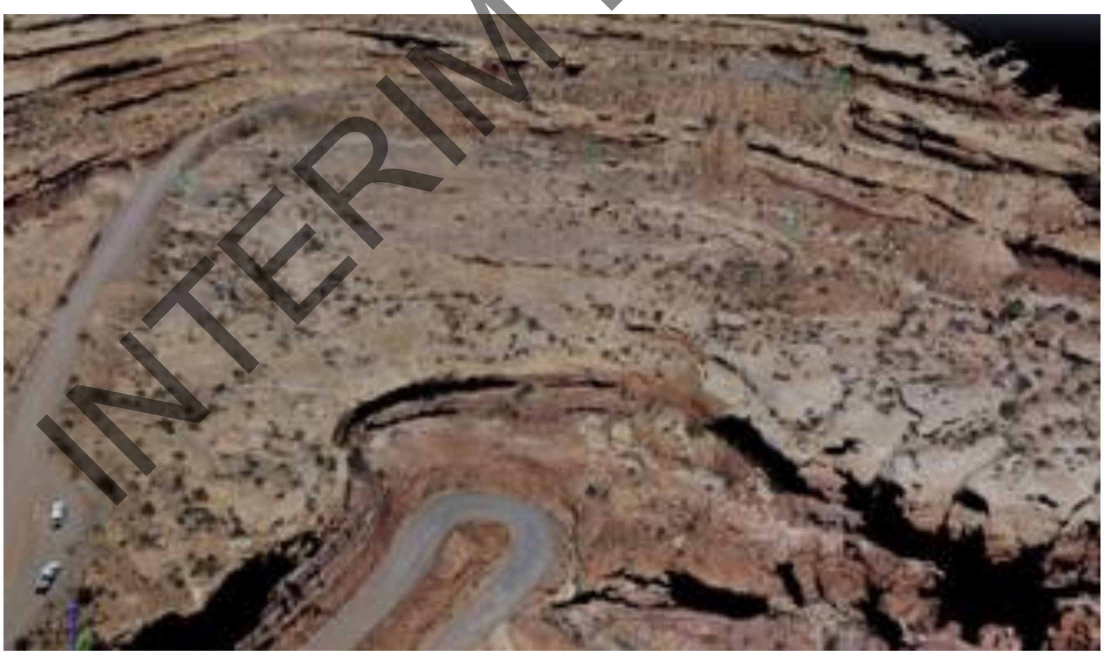
In recent years, lidar surveying has also seen considerable surge in transportation projects. Lidar survey uses laser scanners that emits pulses or waves of light to measure geometry and light reflectance of an object, ultimately creating 3D representation (e.g. point cloud) of the object. The scanner is mounted in multiple configurations making it static (mounted on a Tripod), mobile (mounted on a moving vehicle with other control sensors), and aerial (mounted on an aircraft). Most of these sensors can also be mounted on an Unmanned Aerial Vehicle with necessary support established in the ground can be deployed to conduct aerial survey and obtain rich information about the project site such as orthomosaics, DSMs, and 3D models (Mallela, et al., In Press.). It can make the process cost-effective and quicker than a manned mission for the sane

4.4.2 UAS Integration Opportunities

Operating UAS for surveying and mapping can be performed under Part 107 requirements without a need to secure any waivers; however, some common waivers needed include operating a UAS at night (Part 107.29) and operating outside speed, altitude, and visibility thresholds (Part 107.51). Some other waivers to Part 107 that could potentially be required or obtained to improve use of UAS for surveying and mapping include beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), and operating over people (Part 107.39). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. UAS can effectively map small areas of topography and bathymetry for developing 3D models. Feature extraction using photogrammetric techniques is a significant improvement over traditional methods given the high-resolution of imagery that can be achieved with low-altitude flights. Lidar technology (although more expensive than imagery) provides vegetation penetration and high-resolution point clouds from which to conduct analysis. The coordinate accuracies that can be achieved from imagery and lidar datasets are sufficient for most surveying and mapping applications; however, the elevation accuracies of imagery datasets (and derivative products) is still an area of debate and ambiguity.

With increased penetration of UAS in the market and the improvements in accuracy and efficiency in data collection, surveyors across many state DOTs are testing deployment of UAS technology in surveying and mapping workflows with success. Several DOTs have used UAS for surveying and topographic mapping and developed strategies to integrate the technology into their traditional workflow

UDOT experimented supplementing the existing tools with UAS to enhance the productivity of surveyors while ensuring minimum exposure to dangerous environments (congested traffic conditions in active roadways). The objective was to gather high-quality surveying data that can be used to accomplish various tasks on projects. The sensor package included high-definition cameras (DJI Phantom 12 MP), thermal sensors (SenseFly. Albris TripleView, 38MP), and RGB sensors (Sony RX1RII/35-mm lens, full-frame sensor, 42 MP) mounted on Wingtra Fixed-wing UAS. The agency found that the UAS can fly lower than conventional aircraft and creates opportunities for collecting better quality data including high-resolution imagery and point clouds. The workflow included data collection and automated processing of the data with vendor software. It was also reported that with the help of Ground Control Points, real-time kinematics, and post processing kinematics (PPK) the deliverables can be made with survey-grade quality (Banks et al., 2018) .

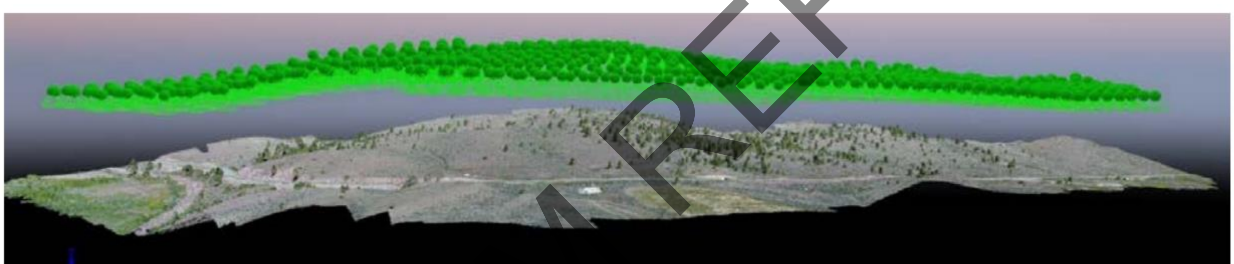


Source: Utah Department of Transportation

Figure 4-9. Image. 3D Point Cloud of Moki Dugway. (Banks et al., 2018)

Montana DOT deployed two UAS equipped with survey-grade GNSS on Lincoln-Rd-West of Green Meadow Project to understand the workflow this technology, compare its accuracy and reliability to the survey data obtained through conventional methods (Beal, 2019). The agency deployed ground control points (GCPs) at not more than 500 feet intervals and post processed kinematics (PPKs). PPK applies correction to the location data from the cameras through the flight location information obtained from a Trimble Base Station set up on a known Control Point. PPK helped maximize the accuracies (vertical: 0.34 feet, horizontal: 0.12 feet) and also reduced the dependency on GCPs to achieve measurements with lowest errors. It was also noted that processing and removal of vegetation data from the site determines the quality of the final model from the survey.

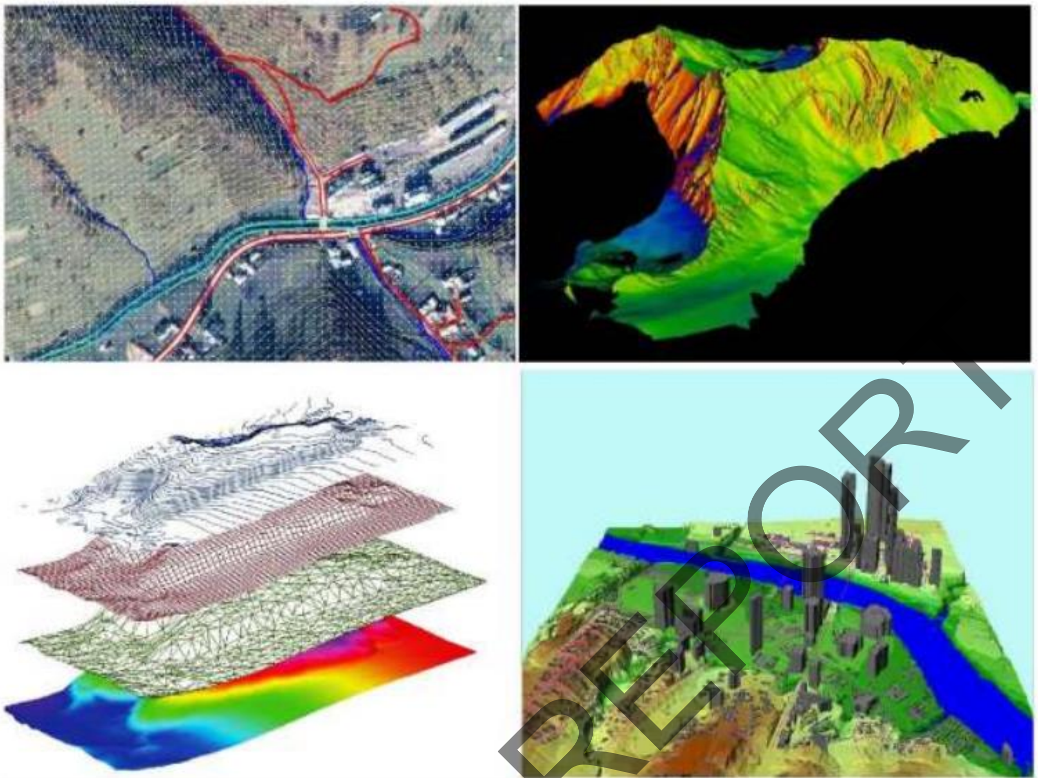
The UAS deployed was a DJI Inspire 2 UAV equipped with a Zenmuse X4S camera and an aftermarket GNSS receiver (LOKI), a remote controller, a mobile device and two software applications (apps) installed on the mobile device (e.g. DJI Go and Map Pilot). Around 1000 photos of the project site were collected and incorporated PPK corrections to enhance accuracy of coordinates in the photos. Pix4D was used to process the images and create a point cloud, orthomosaic, and a DSM. Virtual Surveyor software was used to clean up of DSM of various noises (including Vegetation, People, Buildings etc.) to produce DTM, TIN, and 3D mesh files. Figure 4-10 shows the model along with camera positions during the UAS flights



Source: Montana Department of Transportation

Figure 4-10. Image. Model and Camera View positions. (Beal, 2019)

UAS had also been used to delineate landslides and ascertain risks for highway construction. UAS can be deployed to collect accurate and high-resolution geometric data especially at inaccessible sites. Multiple instances exist in literature where UAS flights were captured images of excavation sites and algorithms such as Structure from motion are used to obtain 3D point clouds of the terrain is extracted to evaluate planes of interest in further detail to estimate the parameters concerning slope stability (Xiao, Kamat, & Lee, 2012), (Danzi, Di Crescenzo, Ramondini, & Santo, 2012) . Figure 4-11 shows the end result after the excavation data is processed using the photogrammetric software



© 2012

Figure 4-11. Images. Slope stability analysis _data processing using SfM. (Xiao et al., 2012)

4.4.3 Benefit/Cost Information

Several state DOTs have positively evaluated the potential of UAS for collecting survey data in a quick and cost-effective manner and as a reliable method to supplement existing techniques for topographic mapping, Lidar surveying, and aerial photogrammetry. Montana DOT reported that the cost of the UAS systems and hardware was just over $10,000, while there were savings in the man-hours spent in collecting data safely and at scale (Beal, 2019).

4.4.4 Assessment

UAS technology is widely used for surveying and mapping activities such as general topographic and planimetric mapping. High accuracy topographic mapping for engineering design is achievable with active sensors such as lidar, but data derived from passive cameras and SfM algorithms are still lacking. The following table illustrates an assessment of the efficacy of UAS technology for surveying and mapping applications.

Table 4-7. Efficacy of using UAS for surveying and mapping. Sources: Federal Highway Administration (2017), Banks et al. (2018).

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	UAS can be used for surveying large mapping areas; it can be used to support and augment the information provided by lidar surveys, Total Stations etc.	Vertical accuracy of UAS and augmenting the details of the resulting models with outputs from other surveying methods may be required.
Efficiency in performing required tasks.	Medium	UAS can fly lower compared to traditional aircrafts, collect information of better quality and produce mapping grade results if augmented with GCPs and PPK.	Post-processing tasks (coordinate correction, noise removal etc.) may involve additional efforts and integrating with other surveying techniques.
Safety improvements	High	UAS for surveying and mapping minimizes the exposure of surveyors to dangerous conditions including active roadways, steep terrains, land slide areas etc.	The presence of UAS flying around structures has the potential to distract drivers and cause incidents. Also, the risks of injury from a UAS impact are a consideration even for the most seasoned remote pilots.
Cost/Labor Savings	Medium	The process maximizes the productivity of labors in data collection process and minimizes the manhours required.	There is increased data processing time to analyze the imagery/video and derive actionable insight.

4.5 Environmental Assessments

Recent developments in imaging and positional accuracy of sensors and data processing techniques have fostered the application of UAS for observation, mapping and assessment of natural and built environments. Potential applications include vegetation mapping, coastline assessment, river morphology assessment, forest management, plant and animal conservation studies. The ability to offer quick, easy, and cost-effective insights about the environment is ushering in an increased use of UAS by researchers, environmental engineers, and conservationists. The use of UAS is usually the preferred alternative especially in areas where manned aircraft services are unavailable or lower resolution satellite imageries would not be able to accomplish the objective.

4.5.1 Traditional Methods

Environmental monitoring and assessment plays a vital role in estimating climate and management impacts on natural and built systems, efficiently allocate and manage water resources, and enhances our disaster preparedness for natural events (Manfreda et al., 2018). While the application of satellite imageries has been on the increase, lower spatial resolution would make the resultant products not suitable for many quantitative applications. Although recent advances in Earth Observations such as CubeSat promises to provide recommended spatial and temporal resolution with maximum spatial coverage, these are operated by private organizations and are often not cost-effective for high-frequency monitoring. Manned aircraft missions present another viable alternative that can provide outputs with requisite resolutions and adequate coverage, their sustained deployment is also often limited by operational complexity, increased safety risks, challenges in logistical planning and potentially higher costs. Use of terrestrial Lidar surveys are less common and used predominantly to conduct detailed studies of smaller areas.

4.5.2 UAS Integration Opportunities

Operating UAS for environmental assessments can be performed under Part 107 requirements without a need to secure any waivers; however, some common waivers needed include operating a UAS at night (Part 107.29) and operating outside speed, altitude, and visibility thresholds (Part 107.51). Some other waivers to Part 107 that could potentially be required or obtained to improve use of UAS for surveying and mapping include beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), and operating over people (Part 107.39). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. UAS can effectively map areas of interest less than 1000 acres in size and derive meaningful insights on environmental conditions using a different sensor types.

UAS technology have considerable potential to cater to a variety of environmental applications given its ability to generate images of significantly higher spatial resolution than satellite solutions (although limited by spatial coverage). Once the initial investment on drone procurement is complete with hardware and software, the datasets can also be delivered at high temporal resolutions by conducting recurring flights at a relatively lower incremental cost. Figure 4-12 compares the coverage capabilities of UAS with other related technologies and identifies the trade-offs between their costs and spatial and temporal resolution.

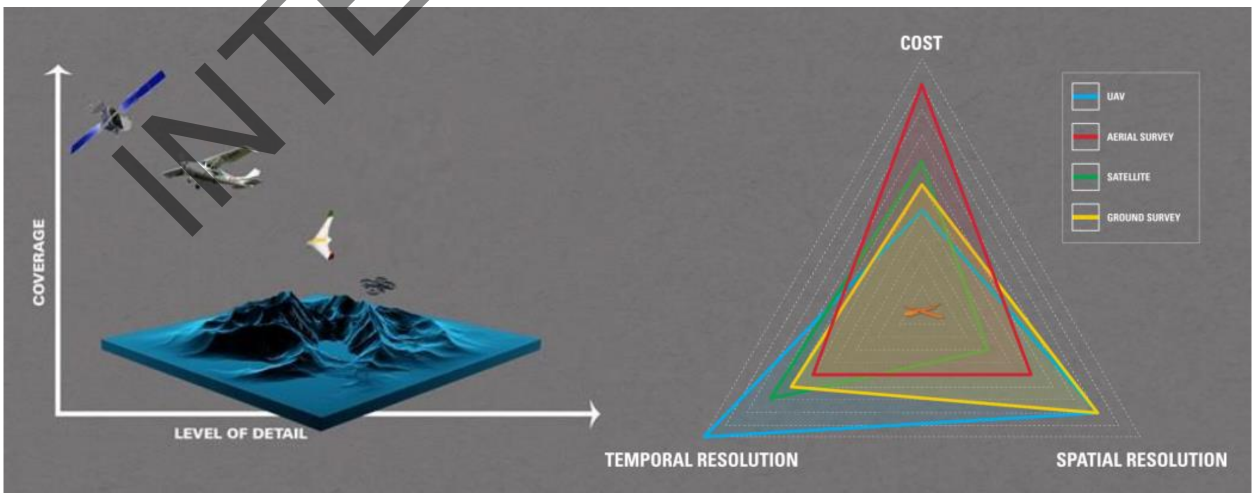


Figure 4-12. Illustration. Trade-offs between cost and resolution of UAS with comparable technologies (Source: (Global Unmanned Systems, 2015)

Like other UAS applications, deployment of UAS for environmental monitoring applications involve the following activities (Manfreda et al., 2018):

Preflight Planning

- Platform specifications, study extents, ground sampling distance, payload characteristics, site topography, weather and atmospheric conditions, local regulations, dereferencing (GCPs), Onboard control (survey-grade GNSS, IMUs),
- Sensors selection: Optical cameras, multispectral cameras, hyperspectral cameras, thermal cameras, laser scanners, SARs

Surveying

- In-flight data collection: Goal of the study, number and frequency of flights (power supply/battery capacity), Radiometric calibration and ground correction.

Post-survey processing:

- Atmospheric correction, orthorectification and image mosaicking, Product extraction
- Data processing Software: Agisoft Photoscan, Pix4D, Open-source SfM software (e.g. VisualSfM, Bundler, Apero-MicMac, OpenDroneMap), Cloud-based platforms (e.g. DroneDeploy or DroneMapper)

4.5.3 Benefit/Cost Information

The typical costs include initial investment of UAV procurement, the processing software, data storage and associated field expenses. The principal benefit of UAS for environmental applications arise from its ability to deliver high-quality datasets with adequate spatial and temporal resolution of the mapping area (vegetation site, coastline.) at necessary frequency. The method is non-intrusive and provides an option to conduct survey of inaccessible areas and dense forest lines. It poses reduced health and safety risks.

4.5.4 Assessment

UAS technology is widely used for mapping environmental conditions given is versatility of rapid deployment and high-resolution data outputs. The following table illustrates an assessment of the efficacy of UAS technology for environmental applications.

Table 4-8. Efficacy of using UAS for environmental assessments. Sources: Global Unmanned Systems (2015), Mandreda et al. (2018).

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	Medium	UAS is a cost-effective support mission and objectives of environmental mapping with adequate resolutions of areas less than 1000 acres.	Areas of interest larger than 1000 acres, are best suited for mapping from a manned aircraft.

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Efficiency in performing required tasks.	Medium	Data can be collected at high level of detail (spatial and temporal resolution) and accuracy if supported by onboard control units and GCPs.	Spatial coverage is generally less than manned aircraft missions and satellite imageries; Processing time could be higher.
Safety improvements	High	It can fly at lower altitude and poses reduced safety risks than manned missions in maneuvering areas of narrower margins.	Line-of-sight UAS are generally applicable for studies in limited areas, less than 1000 acres, as it has potential safety implication and operational constraints.
Cost/Labor Savings	Medium	Reduced labor costs due to savings in man-hours spent on in-field; Cost savings due to reduced operator costs for recurring flights to increase temporal resolution.	Increased data processing time at the office and lower spatial coverage.

4.6 Emergency and Incident Response/Recovery – Natural Disasters

The use of UAS has made significant strides in providing valuable insights for emergency responders during various natural disasters including flooding, wildfires, landslides and other events. Many of these situations poses operational, safety, and accessibility challenges for surveying and reconnaissance efforts to monitor impacted areas. The characteristics of UAS technology is suitable to assist in such operations for enhanced situational awareness, risk assessment for response activities, and to collect data to assess the damage for repair and rehabilitation efforts.

4.6.1 Traditional Methods

Emergency response is mission critical for all DOTs and a crucial stage in the disaster management cycle predominantly focusing on warning, evacuation, search and rescuing efforts, and damage assessments to ensure appropriate repair and rehabilitation efforts are being put into action. Damage assessment is vital to request federal emergency declarations for both FHWA Emergency Relief program and FEMA's Public Assistance (PA) programs. Typical methods of damage assessment include aerial surveys using manned aircraft missions or satellite vehicles to collect images and videos of affected areas. Depending on the extent of the damage, deploying manned aircraft may not be cost-effective and often be inadequate to provide complete and detailed information of the extent and severity of damages involved. 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 extended period. In the U.S., such information comes from National Oceanic and Atmospheric Administration, to commercial providers such as DigitalGlobe, Planet, and Cubesat (Duffy, 2018)

To obtain complete picture of the damage, imagery from multiple service providers, both public and private must be combined including other sensors such as SAW (that collects damage information regardless of lighting and weather condition), shortwave Infrared Band (SIWR) band of optical sensors (that illuminates hot spots in a region of wildfire. Most of these sensors can be conveniently deployed on a UAS to survey the areas with adequate spatial and temporal resolution in a cost-effective manner.

4.6.2 UAS Integration Opportunities

Operating UAS for emergency and incident response/recovery likely requires additional flexibility beyond Part 107 requirements. Access to airspace (to avoid conflicts with search and rescue efforts) and securing Part 107 waivers are important considerations for using UAS during response and recovery operations to obtain sufficient situational awareness and assess risk. Some waivers to Part 107 that could be required or obtained to improve use of UAS for emergency and incident response/recovery include operating a UAS at night (Part 107.29), beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), operating over people (Part 107.39), and operating outside speed, altitude, and visibility thresholds (Part 107.51). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. Establishing the required protocols and safety management systems early in the preparedness stage are important so when the disaster/incident occurs, rapid deployment is achievable.

During preparedness activities, interagency agreements (e.g. memorandums of agreement/understanding) can be structured to incorporate specific UAS tasking protocols to ensure UAS technology is an integral part of the planning and eventual response/recovery efforts. This streamlines the construction of temporary facilities immediate after the event.

UAS has proven to be valuable tool for emergency response during major natural disasters including flooding, landslides, avalanches, hurricanes, and wildfires among others. Broadly speaking, UAS was used for damage assessment studies post the natural disaster, assist in rescue and rehabilitation efforts and supply of relief and welfare services. Following are some of the noted applications of UAS in response to natural disaster events

- **Nuclear reactors damage assessment:** In Fukushima, Japan, Engineers used an UAV with a camera to obtain images of the damaged reactors during an earthquake triggered by Tsunami in March 2011 across northern Japan. Drones provided images of the reactors that are used to assess the extent of the damage and pools of spent fuel inside (Smith, 2011). They were able to provide immediate extent of the destruction, delivering assistance in monitoring radiation exposure and repair and rehabilitation efforts of the destroyed areas. There were also reports that UAS technology was deployed to provide food and medical assistance to residents of a town where access to shops is limited (“Drone delivers food to Fukushima town,” 2017)

Figure 4-13. Photo. Image captured using UAV showing damaged nuclear power plant (Source: Smith, 2011).

- **Flood mapping and assessment**: UAS have also been increasingly used to collect imageries and 3D mapping especially in areas where manned aircraft missions and satellite are operationally infeasible or inadequate to meet the resolution needs. Several variety of UAS use have been recorded in the Y.S. during flood events 2005. FHWA found that at least 12 state DOTs used UAS in response to flooding (Murphy, 2019). A few notable examples are listed below
    - **Hurricane Katrina 2005**: Rotorcraft and Fixed-wing UAS deployment to study flood crest of Pearl River in Louisiana and Mississippi and estimate risk to surrounding communities
    - **Hurricane Wilma 2005:** Examine the bridge to Fort Myers Beach off the southwest Florida
    - **Blanco River, Texas, 2015:** UAS used to search for missing persons swept away in floods into inaccessible areas of floods
    - **Hurricane Harvey, 2017:** UAS was deployed by Office of Emergency Management, Fort bend, TX, to support emergency management pre-, during, and post-flood (around 112 flights were made in Total). Figure 4-14 below shows imagery and 3D DEM created during the flood event in Hurricane Harvey.
    - **Hurricane Florence, 2018:** NCDOT had deployed UAS to assess the extent of flooding on major roadways. NCDOT flew more than 260 drone missions and capture more than 8,000 videos and images of roads, bridges, and dams. NCDOT assisted other state agencies in a range of condition assessments. (North Carolina Department of Transportation, 2018)
    - UAS also has significant potential in monitoring erosion over riverbeds on the aftermath of flooding. A three-year study conducted by a team from UVM's Special Analysis Lab flew 50 miles of the Winooski, New Haven, and Mad Rivers and monitoring one particular site prone to significant erosion so that mitigation strategies can be developed (Viglienzoni, 2019).

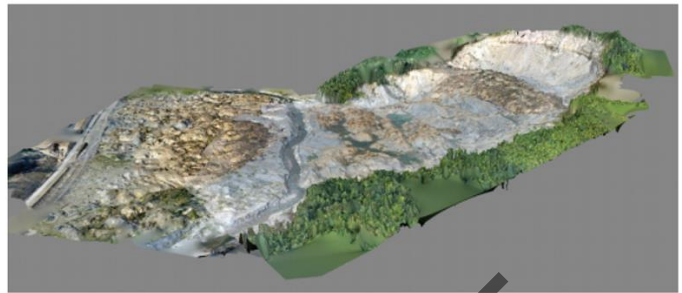



Figure 4-14. Imagery (left) and 3D DEM (Right). (Center for Robot-Assisted Search and Rescue (CRASAR))

- **Managing Wildfires**: UAS can eliminate the safety risks that pilots face and help develop effective strategies to combat forest fires, and provide greater situational awareness. They can also fly at lower altitudes to drop fire retardants accurately and safely. Drones can also act as intermediary communication systems between command center and rescue operators on the ground. The Los Angeles Fire Department used two drones to combat Southern California Wildfires, the first quadcopter enabled survey of damaged property and map the path of the fire, and the second one with an infrared camera to spot hotspots precisely to extinguish them

4.6.3 Benefit/Cost Information

Literature does not indicate specific studies where the costs to benefits were compared for using UAV to emergency response rising from natural disasters. Most of the costs are incurred as initial investments of purchasing UAS and developing operational protocols for using them for surveys. Benefits are often invaluable that would include potential life and property savings through elimination of manned survey missions into the areas that are dangerous for human access, lives saved from rescue and relief efforts. Benefits also arise due to improved data quality in terms of adequate spatial and temporal resolution for damage assessment, continuous monitoring, and planning for rescue and rehabilitation efforts.

4.6.4 Assessment

UAS technology is continually being evaluated by emergency responders given its ability to deliver heightened situational awareness and assess risks. The following table illustrates an assessment of the efficacy of UAS technology for natural disaster emergency response applications.

Table 4-9. Efficacy of using UAS for emergency response (natural). Sources: Murphy (2019)

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	UAS can effectively support for post-disaster survey and reconnaissance efforts and will be invaluable for assisting rescue and rehabilitation efforts.	Spatial coverage may be a limiting factor in data. UAS operations may be limited especially in case if BLOS operations are not allowed.
Efficiency in performing required tasks.	Medium	UAS can provide 3D mapping and imagery data of the affected areas with high spatial and	It requires trained personnel who could operate drones

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
		temporal resolution necessary to assess damages and support relief and welfare efforts.	efficiently in constrained environments.
Safety improvements	High	Potential life and property savings due to avoidance of manned surveys, life savings from assisted rescue and relief efforts.	Trained operations crew required to create successful flight plans and execute them.
Cost/Labor Savings	Medium	Labor savings due to Rapid data collection of situations arising from natural disaster and reduction in direct labor costs (manhours) involved in data collection.	Increased data processing time in the office to make actionable insights.

4.7 Emergency and Incident Response/Recovery – Human-caused Disasters

Human-caused disasters on transportation systems, such as traffic crashes or hazardous chemical spills create intricate challenges in monitoring them and planning for restoration strategies. It is often needed to record evidences from the scene of disaster to use them for evaluating the causes to support any legal requirements. UAS can be deployed effectively in such situations to assist human operators and law enforcement agencies in collecting the required information quickly and safely.

4.7.1 Traditional Methods

Traditional methods of evaluating scenes of human-caused disasters often involve site investigation to determine the primary causes of accident, assess injuries, potential fatalities, and property damages, and record all key details that would help in subsequent investigation process off site. The site investigation procedure often entails fencing off and detailed recording (tour) off the crash site to record status and condition of the vehicles, commuters, and damage to assets (if any). Manual sketching or photographs of the scene is often taken to support the crash documentation. The methodology, as a whole, could be time-consuming and interrupt, delay the restoration of the transportation link to free-flow of traffic. Hazardous Chemical spills also represent another potential situation that adversely impact the safety of the moving traffic in the highway system. While crash statistics at the national level indicate such incidences are relatively rare than vehicular collisions on highways, the ensuing danger from such occurrences pose significant challenge in ensuring safe vehicular travel.

While UAS cannot support all the information requirements necessary to understand the scene and do not provide, by itself, all the background evidence required to support an investigation, they can be used to recreate crash scenes with significant level of detail. As such, it can be successfully integrated with other modes of data collection. FHWA has reported that secondary crashes, that occur in the scenes/queues of the crash site due to the hours spent in conventional record/mapping, are often much higher than the original source. Drones can assist in drastically reducing the likelihood of secondary crashes (Cynthia, 2019)

4.7.2 UAS Integration Opportunities

Operating UAS for emergency and incident response/recovery likely requires additional flexibility beyond Part 107 requirements. Access to airspace (to avoid conflicts with search and rescue efforts) and securing Part 107 waivers are important considerations for using UAS during response and recovery operations to obtain sufficient situational awareness and assess risk. Some waivers to Part 107 that could be required or obtained to improve use of UAS for emergency and incident response/recovery include operating a UAS at night (Part 107.29), beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), operating over people (Part 107.39), and operating outside speed, altitude, and visibility thresholds (Part 107.51). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. Establishing the required protocols and safety management systems early in the preparedness stage are important so when the disaster/incident occurs, rapid deployment is achievable.

During preparedness activities, interagency agreements (e.g. memorandums of agreement/understanding) can be structured to incorporate specific UAS tasking protocols to ensure UAS technology is an integral part of the response/recovery efforts. This streamlines the site documentation and data sharing between agencies.

UAS technology has been piloted for crash scene reconstruction in many DOTs, local transportation agencies, Counties, and law enforcement officials. A research team in Purdue University developed photogrammetric procedures for processing and mapping crash scenes from the data collected using a UAS in five to eight minutes (Cynthia, 2019). The Tippecanoe County Sheriff's Office had used UAS to map crash scenes around 35 times in 2018 to support law enforcement officials in the county and neighboring jurisdictions. In some instances, they also created 3D Printed models to support engineers and public safety officials study (mimic) the crash scenes (Figure 4-15)

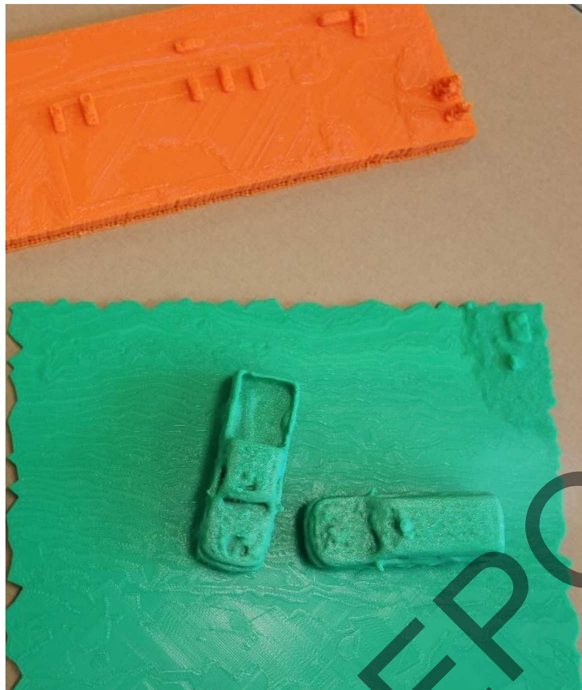


Figure 4-15. Photo. 3D Print of accident scenes. Source: Erin Easterling /Purdue University

The Ontario Provincial Police (OPP), uses UAV technology for multiple objectives in incident management including forensic identification and collision scene mapping which was made necessary as part of rapid clearance mandate within the Highway Safety Division (HSD). The imageries so obtained from these UAV flights can be stitched together using multiple vintage points to create 3-D visual reconstruction of the collision scene with competent accuracy (1 cm/pixel). The specifications of the UAV used, Aeryon Scout, are mentioned in Table 4-10.

Table 4-10. Aeryon Scout specifications (Kamga et al., 2017).

General Characteristics	
Length	80 cm (28.2 in)
Rotor Diameter	80 cm (28.2 in)
Height	30 cm (1 ft.)
Loaded Weight	1.4 kg (3.1 lbs.)
Maximum Takeoff Weight	1.7 kg (3.74 lbs.)
Propulsion	4 x electric motor with intelligent LiPo battery
Propeller Diameter	30 cm (1 ft.)
Maximum Speed	50 km/hr. (31 mph)
Cruise Speed	40 km/hr. (25 mph)
Range	3 km (2 mi)
Service Ceiling	3000 m (1000 ft.) AGL/5000 m (15000 ft.) ASL
Rate of Climb	2 m/s (6 ft./s)

Michigan DOT conducted demonstrations of UAV implementation for multiple local agencies and law enforcement authorities including Michigan State Police, Southeast Oakland County using small quadcopters and hexacopter (DJI Phantoms equipped with GoPro cameras and quick and lower resolution images). The collected imageries can be processed using photogrammetric software such as PiX4D to perform various evaluations and create datasets supporting the incident management initiatives. Figure below shows the 3D mesh model created from an accident scene (Kamga et al., 2017).

Figure 4-16. Image. 3D mesh model of accident scenes (Kamga et al., 2017).

TxDOT worked with researchers from Texas A&M Transportation Institute to demonstrate use of UAS for Traffic Incident Management including several missions such as traffic monitoring, incident detection and response, enhance situational awareness, and map crash scenes. While they observed that the image quality was not significantly higher than currently used camera, they were beneficial since the system is mobile, easily repairable (than fixed systems), and enable innovative ways of scene reconstruction in greater detail. Key factors to consider include response time, remote launching, UAS for special events and public facilities, and UAS use over people, vehicles, and property (Stevens Jr. & Blackstock, 2017).

4.7.3 Benefit/Cost Information

Using UAS for incident management is an emerging thrust area among various applications of UAS with significant potential to provide a variety of information on crash scenes- orthomosaics, videos 3D mesh models, 3D printed models, etc. The major cost involved is investment to procure and deploy the UAS on scene, along with operational standards and permits to safely operate over the site of active traffic. Benefits include comprehensive and faster documentation of crash sense leading to time saved in inspecting the scene and collecting relevant information, potential reduction in number of secondary crashes, and measurable digital outputs that can be used as evidence in court.

NCDOT in collaboration with NC Highway Safety Patrol simulated a head-on crash in controlled environment. While the HSP’s Collision Reconstruction Unit took 2 hours in data collection, pilots using UAS took 25 minutes. The savings were also monetized by considering $8,600 per hour per lane in lost productivity if the crash had to occur on I-95. While traditional methods would have costed $12,900, UAS use would have costed $3,600 or resulted in $9,300 savings (North Carolina Department of Transportation, 2017).

4.7.4 Assessment

UAS technology is continually being evaluated by emergency responders given its ability to deliver heightened situational awareness and assess risks. The following table illustrates an assessment of the efficacy of UAS technology for human-caused disaster emergency response applications.

Table 4-11. Efficacy of using UAS for emergency response (human-caused). Sources: Kamga et al. (2017), NCDOT (2017)

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	Incident management and scene recreation through UAS technology presents a safe, quicker approach for traffic monitoring and data collection to support forensic investigations.	The managerial practices and legal protocols enabling frequent use of UAS for traffic incident management is still being developed in many state DOTs.
Efficiency in performing required tasks.	Medium	Collected data assist in obtaining situational awareness and can be processed to obtain a variety of digital outputs including videos, orthomosaics, 3D models to support investigations.	The information may need to be supplemented by other form of manual inputs to ensure all the key background information is captured.
Safety improvements	High	Use of UAS for incident management leads to direct safety benefits by reducing the time spent in onsite investigation, reducing the likelihood of secondary crashes, and assisting in quick clearance of the impacted corridor.	UAS operations for mapping crash scenes may cause distraction to other drivers in live traffic and could pose a safety threat that can lead to other incidents.
Cost/Labor Savings	Medium	Time savings in onsite investigation and documentation of necessary evidence.	There is a potential for increased processing time if there is a need to collect accurate and detailed information on crash site.

4.8 Public Outreach and Engagement

Public outreach and engagement efforts for transportation projects plays an important role in successful project delivery aligning with the original objective of benefitting the communities. It is not uncommon to utilize a separate public information and communication team at the agency-level or at least on projects of large scale and complexity to assist in dispensation of timely information and garner public buy-in for the concept and continuous support during various phases of project delivery.

4.8.1 Traditional Methods

State DOTs and consultants deploy a wide variety of outreach mediums to communicate the status of the project from conception through design and construction. These engagement techniques include project websites, videos, social media, news reports, public information meetings that provides timely awareness and valuable information about the anticipated improvements and temporary disruptions a project can cause. Some state DOTs also perform extensive community outreach initiatives to communicate and harness support of impacted communities including goody bags containing pamphlets describing the benefits of project, and importance of stakeholder's participation in success of projects. UAS can play a significant role in enhancing the efficiency of the public outreach and demonstration efforts as described below in a few case studies

4.8.2 UAS Integration Opportunities

Operating UAS for public outreach and engagement can largely be performed under Part 107 requirements without a need to secure any waivers. Some waivers to Part 107 that could potentially be required or obtained to improve use of UAS for public outreach and engagement include beyond visual line of sight (Part 107.31), limiting the use of a visual observer (Part 107.33), operating multiple UAS with a single remote pilot (Part 107.35), operating over people (Part 107.39), and operating outside speed, altitude, and visibility thresholds (Part 107.51). The challenges in securing these waivers vary significantly and may require significant analysis to prove safe operations, which could limit integration opportunities. UAS can provide timely aerial imagery and video at a high resolution for a more immersive perspective of undeveloped land for upcoming projects, for monitoring projects under construction, or for other activities that have significant public interest. This immersive perspective is hard to achieve from ground-based photography/video or from manned aerial platforms such as helicopters or fixed-wing aircraft.

NCDOT had used videos obtained from an UAV to create a bird's-eye perspective of a roundabout project to demonstrate to public about working characteristics, mobility enhancement, and increased safety offered by roundabouts. The videos were proven effective to engage and educate public about the roundabout. The videos were hosted in website and social media platform making them available at the convenience of any user beyond the timeline of the public meetings. NCDOT also reported that the video played a crucial role in harnessing buy-in of public stakeholders, who are initially opposed to the idea of roundabouts (North Carolina Department of Transportation, 2019).

Instances exist in literature where images and videos obtained from UAV deployed on construction job-sites were used to generate time-lapse videos that can be used for public information. A simple video obtained from an UAV can assist the viewer in understanding project details from various perspectives and gather holistic details that cannot be obtained otherwise from the ground. They can also be more effective in creating affirmative atmosphere communicating project progress in place of flyers or information bullets (Khaled, 2018).

Figure 4-17. Photo. UAV being used for time-lapse videos of construction progress.

4.8.3 Benefit/Cost Information

While the benefits of UAV use are not directly quantified in the literature, instances of the technology use for public outreach efforts have positively evaluated the net benefits. As expected, the key investments are in procuring the UAS and developing supportive operational and legal protocols. Key benefits include increased effectiveness in accomplishing the objectives for public information such as increased situational and contextual awareness of the public, increased likelihood of initial and continuous support for project success, and augmentation of successful chance with other mediums.

4.8.4 Assessment

UAS technology is widely used for visualization and public engagement. The videos and images collected from UAS provide high fidelity of existing conditions, which helps convey valuable information about projects or other activities. The following table illustrates an assessment of the efficacy of UAS technology for public education and outreach applications.

Table 4-12. Efficacy of using UAS for public outreach and engagement. Sources: NCDOT (2019), Khaled (2018).

Criteria	Measure (high, medium, low)	Advantages	Deficiencies
Effectiveness in achieving objectives	High	UAS can be used to support the effectiveness of various public outreach and engagement techniques in obtaining stakeholder buy-ins and increased awareness of the project.	The technology has limitations in being a stand-alone tool for stakeholder engagement.
Efficiency in performing required tasks.	Medium	Data collected include videos that can be used for project demonstration and time-lapse images that can be used to communicate project progress with ease and adequate level of detail.	Understanding of time-lapse videos and drone footage may need supplementation with other techniques.
Safety improvements	Low	Deploying UAS for collecting data for public outreach likely has similar safety risks for pilots and commuters in comparison to photos and videos obtained by any other means.	Operating UAS over jobsite/traffic may be a source of distraction for workers/drives and could act as a new source of hazard increasing the likelihood of accidents.
Cost/Labor Savings	Medium	Savings in man-hours spent in collecting detailed images and videos for public demonstration.	Potential increase in the processing time of the data collected to deliver actionable items for public outreach efforts.

5.0 SELECTED TRANSPORTATION APPLICATIONS AND NEXT STEPS

Based on the findings from the literature review, the preferences of New England state DOTs, and the interviews with notable DOTs with mature practices, the research team was able to identify applications ripe for implementation. The research team was able to assign a use case for each New England state DOT for further investigation as shown below in Table 5-1. Once the research team receives concurrence on these use cases, the research team will identify and analyze the UAS technologies that are necessary to implement the use cases (including relevant support systems or infrastructure).

Table 5-1. Recommended applications for investigation.

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

6.0 REFERENCES

Alabama Department of Transportation. (2017). *Unmanned Aircraft System—Standard Operating Procedure*.

American Association of State Highway and Transportation Officials. (2019, May). *Special Report: The Evolution of Drones Part 3: Building Highways in the Sky*. Retrieved from https://www.transportation.org/the-evolution-of-drones-part-3/

Association for Unmanned Vehicle Systems International. (2019). STATE LEGISLATION MAP: UNMANNED SYSTEMS. Retrieved August 8, 2019, from https://public.tableau.com/views/AUVSI/PriorityBills?:embed=y&:showVizHome=no&:host_url=https%3A%2F%2Fpublic.tableau.com%2F&:tabs=yes&:toolbar=no&:animate_transition=yes&:display_static_image=no&:display_spinner=no&:display_overlay=yes&:display_count=yes&:loadOrderID=0

Banks, E., Cook, S. J., Fredrick, G., Gill, S., Gray, J. S., Larue, T., … Snyder, P. R. (2018). *Successful Approaches for the Use of Unmanned Aerial Systems by Surface Transportation Agencies*.

Barnes, P., & Turkel, E. (2017). *Autonomous Vehicles in Delaware: Analyzing the Impact and Readiness for the First State*. Institute for Public Administration, University of Delaware.

Beal, F. (2019, February). *Small Unmanned Aerial System (sUAS or UAS) Mapping Accuracy Test*. Retrieved from https://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH_PROJ/UAV/REF_MAT/8939_LINCOLN.pdf

Carroll, E. A., & Rathbone, D. B. (2008, June 3). *Using an Unmanned Airborne Data Acquisition System (ADAS) for Traffic Surveillance, Monitoring, and Management*. 145–157. https://doi.org/10.1115/IMECE2002-32916

Crumal, Z. (2017, April). What is a Robotic Total Station? Here's Everything You Need to Know. Retrieved August 8, 2019, from https://connect.bim360.autodesk.com/what-is-a-robotic-total-station

Connecticut Department of Transportation. (2018a, March). *CTDOT, Long Range Transportation Plan, 2018-2040*. Retrieved from https://portal.ct.gov/-/media/DOT/documents/dpolicy/lrp/2018lrp/FINALConnecticutSLRTP20180313pdf.pdf?la=en

Connecticut Department of Transportation. (2018b, July). *CTDOT Highway Transportation Asset Management Plan*. Retrieved from https://portal.ct.gov/-/media/DOT/documents/dplansprojectsstudies/plans/CTDOTTAMPFHWAcertified20180724pdf.pdf

Connecticut Department of Transportation. (2019). About Connecticut DOT: Our Mission, Values. Retrieved August 12, 2019, from CT.gov—Connecticut's Official State Website website: http://portal.ct.gov/DOT/General/Commissioners-Greeting

Cynthia, S. (2019, January). Drones shown to make traffic crash site assessments safer, faster and more accurate. Retrieved August 9, 2019, from Purdue News Service website: https://www.purdue.edu/newsroom/releases/2019/Q1/drones-shown-to-make-traffic-crash-site-assessments-safer,-faster-and-more-accurate.html

Danzi, M., Di Crescenzo, G., Ramondini, M., & Santo, A. (2012). Use of unmanned aerial vehicles (UAVs) for photogrammetric surveys in rockfall instability studies. *Rend. Online Soc. Geol. Ital*, *24*, 82–85.

DataFromSky. (2019). Traffic counting. Retrieved September 5, 2019, from DataFromSky website: http://datafromsky.com/applications/traffic-counting/

DeCarlo, J. (2017, October). *Drone Interim Policy*. Presented at the MassDOT Board Meeting. Retrieved from https://www.mass.gov/files/documents/2017/10/17/DronePolicy_101617.pdf

Delabruere, D. (2019, March). *VTRANS UAS UNMANNED AIRCRAFT SYSTEMS*. Presented at the Workgroup: Senate Transportation Vtrans Aviation Testimony. Retrieved from https://legislature.vermont.gov/Documents/2020/WorkGroups/Senate%20Transportation/VTrans%20Aviation%20Testimony/W~Dan%20Delabruere~VTrans%20Unmanned%20Aircraft%20Systems%20(UAS)~3-14-2019.pdf

Drone delivers food to Fukushima town. (2017, November 1). *BBC News*. Retrieved from https://www.bbc.com/news/business-41827634

Duffy, L. (2018, October). Fighting Natural Disasters with Satellite Imagery. Retrieved August 8, 2019, from https://www.pobonline.com/articles/101492-fighting-natural-disasters-with-satellite-imagery

Federal Aviation Administration. (2016). E-CFR Title 14 Part 107. Retrieved August 5, 2019, from ECFR.io website: https://ECFR.io/Title-14/cfr107_main

Federal Aviation Administration. (2016a, June). *AC-107-2: Small Unmanned Aircraft Systems (sUAS)*. Retrieved from https://www.faa.gov/uas/resources/policy_library/media/AC_107-2_AFS-1_Signed.pdf

Federal Aviation Administration. (2016b, August). *Remote Pilot – Small Unmanned Aircraft Systems Study Guide*. Retrieved from https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf

Federal Aviation Administration. (2017). Safety Management System – Components [Template]. Retrieved August 5, 2019, from https://www.faa.gov/about/initiatives/sms/explained/components/

Federal Aviation Administration. (2019). UAS Data Exchange (LAANC) [Template]. Retrieved August 5, 2019, from https://www.faa.gov/uas/programs_partnerships/data_exchange/

Federal Emergency Management Agency. (2019). 03OE-07-SUAS | FEMA.gov. Retrieved September 5, 2019, from https://www.fema.gov/authorized-equipment-list-item/03oe-07-suas

Federal Highway Administration. (2012). *Bridge Inspector's Reference Manual*. Retrieved from https://www.fhwa.dot.gov/bridge/nbis/pubs/nhi12049.pdf

Federal Highway Administration. (2016a). Capability Maturity Frameworks for Transportation Systems Management and Operations Program Areas. Retrieved September 13, 2019, from https://ops.fhwa.dot.gov/publications/fhwahop16031/index.htm

Federal Highway Administration. (2016b, October). *Traffic Monitoring Guide*. Retrieved from https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_fhwa_pl_17_003.pdf

Federal Highway Administration. (2018). Use of Unmanned Aerial Systems (UAS) by State DOTs. Retrieved from https://www.fhwa.dot.gov/uas/peer/2018peer.pdf

Federal Highway Administration. (2019a). *Peer-to-Peer Exchange: Delaware, Michigan, and Utah Departments of Transportation; Kentucky Transportation Cabinet; Ohio Facilities Construction Commission; and New York State Thruway Authority*. Retrieved from https://www.fhwa.dot.gov/construction/econstruction/hif19065.pdf

Federal Highway Administration. (2019b). Active Traffic Management: Approaches: Active Transportation and Demand Management—FHWA Operations. Retrieved September 5, 2019, from https://ops.fhwa.dot.gov/atdm/approaches/atm.htm

Gheisari, M., Irizarry, J., & Walker, B. N. (2014). UAS4SAFETY: The potential of unmanned aerial systems for construction safety applications. *Construction Research Congress 2014: Construction in a Global Network*, 1801–1810.

Global Unmanned Systems. (2015, April). *Use of Unmanned Aerial Vehicles (UAVs) in Impact Assessment*. Presented at the International Association for Impact Assessment, Florence, Italy. Retrieved from https://conferences.iaia.org/2015/Final-Papers/Use%20of%20UAVs%20in%20Impact%20Assessment.pdf

Govdelivery.com. (2018, April 25). ADOT gains drones through federal innovation program. Retrieved August 5, 2019, from Arizona Department of Transportation website: https://content.govdelivery.com/accounts/AZDOT/bulletins/1ec2ada

Kamga, C., Sapphire, J., Moghimidarzi, B., & Khryashchev, D. (2017). *Exploring Applications for Unmanned Aerial Systems and Unmanned Ground Systems in Enhanced Incident Management, Bridge nspection, and Other Transportation-related Operations* (No. C-15–01). NY: New York State Department Transportation.

Khaled, P. (2018, February 8). Construction Time Lapse Videos through a drone—An Unmanned Aerial Vehicle (UAV). Retrieved August 9, 2019, from Medium website: https://medium.com/@mdstudio52/construction-time-lapse-videos-through-a-drone-an-unmanned-aerial-vehicle-uav-75015d061289

Lovelace, B. (2018). *Improving the Quality of Bridge Inspections Using Unmanned Aircraft Systems (UAS)*. Retrieved from Minnesota DOT website: http://www.dot.state.mn.us/research/reports/2018/201826.pdf

Maine Department of Transportation. (2014). *Data and Systems Governance Framework*.

Maine Department of Transportation. (2018). About MaineDOT. Retrieved August 20, 2019, from https://www.maine.gov/mdot/about/

Maine Department of Transportation. (2019a). *UAS Standard Operating Procedure*.

Maine Department of Transportation. (2019b, February). *Work Plan Calendar Years 2019-2020-2021*. Retrieved from https://www.maine.gov/mdot/projects/workplan/docs/2019/Work-Plan-2019-2020-2021-Feb-2019.pdf

Maine Department of Transportation. (2019c, June). *Transportation Asset Management Plan*. Retrieved from https://www.maine.gov/mdot/publications/docs/plansreports/MaineDOT-Transportation-Asset-Management-Plan-final.pdf

Mallela, J., Mitchell, A., Gustafson, J., Olsen, M., Parrish, M., Kumpula, M., & Roe, G. (In Press). *Effective Use of Geospatial Tools in Highway Construction*. McLean VA: FHWA. Draft Final Report Retrieved from https://research.transportation.org/wp-content/plugins/AASHTO_RAC/download_file.php?fileid=571

Manfreda, S., McCabe, M., Miller, P., Lucas, R., Pajuelo Madrigal, V., Mallinis, G., … Ciraolo, G. (2018). On the use of unmanned aerial systems for environmental monitoring. *Remote Sensing*, *10*(4), 641.

Massachusetts Department of Transportation. (2018). *Performance and Asset Management Advisory Council: ANNUAL REPORT*. Retrieved from https://www.mass.gov/files/documents/2019/01/02/2018_PAMAC_AnnualReport.pdf?_ga=2.2483760.1802688114.1565723152-2140278237.1565723152

Massachusetts Department of Transportation. (2019a). Funding considerations. Retrieved August 13, 2019, from Mass.gov website: https://www.mass.gov/service-details/funding-considerations

Massachusetts Department of Transportation. (2019b, May 21). *2020-2024 Draft State Transportation Improvement Program*. Retrieved from https://www.mass.gov/files/documents/2019/05/21/FFY20_24STIP.pdf

McGuire, M., Rhys, M., & Rhys, A. (2016, August). *A Study of How Unmanned Aircraft Systems Can Support the Kansas Department of Transportation's Efforts to Improve Efficiency, Safety, and Cost Reduction*. Retrieved from https://rosap.ntl.bts.gov/view/dot/31030/dot_31030_DS1.pdf

Mihaley, A. (2019, April). *Massachusetts Drone Program: Expanding Operations Across the Commonwealth*. Presented at the 2019 MassDOT Innovation Conference. Retrieved from https://www.umasstransportationcenter.org/Document.asp?DocID=687

Montana Department of Transportation. (2017). Construction Engineering Services Bureau UAS Standard Operating Procedures 8-18-17 Updated. Retrieved from https://transportation.libguides.com/ld.php?content_id=41793076

Murphy, R. (2019, May). *Tech Brief: USE OF SMALL UNMANNED AERIAL SYSTEMS FOR EMERGENCY MANAGEMENT OF FLOODING*. Retrieved from https://www.fhwa.dot.gov/uas/resources/hif19019.pdf

National Oceanic and Atmospheric Administration. (2019). Climate Monitoring | National Centers for Environmental Information (NCEI). Retrieved September 5, 2019, from https://www.ncdc.noaa.gov/climate-monitoring/national/43/3/201907

New Hampshire Department of Transportation. (2019, June). *Asset Management Plan for Pavements & Bridges on the National Highway System*. Retrieved from https://www.nh.gov/dot/org/commissioner/amps/documents/tamp-2019-nhdot.pdf

North Carolina Department of Transportation. (2017, August). *COLLISION SCENE RECONSTRUCTION & INVESTIGATION USING UNMANNED AIRCRAFT SYSTEMS*. Retrieved from https://www.ncdot.gov/divisions/aviation/Documents/ncshp-uas-mapping-study.pdf

North Carolina Department of Transportation. (2019, April). NCDOT Roundabouts—YouTube. Retrieved August 9, 2019, from https://www.youtube.com/watch?v=eZyccYCsyZM&feature=youtu.be

O'Neil-Dunne, J. (2017). *Vtrans Fact Sheet: Unmanned Aerial Systems for Transportation Decision Support*. Retrieved from https://vtrans.vermont.gov/sites/aot/files/planning/documents/planning/UAS%20for%20Transportation%20Fact%20Sheet.pdf

Otero, L. D. (2015). *Proof of concept for using unmanned aerial vehicles for high mast pole and bridge inspections.* Florida. Dept. of Transportation. Research Center.

Pennsylvania Department of Transportation. (2019, April). *Unmanned Aircraft System (UAS) Policy, Version 1.0*. Retrieved from http://www.paconstructors.org/wp-content/uploads/2019/06/PennDOT-UAS-Policy-Ver-1.0Apr2019.pdf

Rhode Island Department of Transportation. (2019a). About Us—Rhode Island Rhode Island Department of Transportation. Retrieved August 16, 2019, from http://www.dot.ri.gov/about/index.php

Rhode Island Department of Transportation. (2019b, June). *TRANSPORTATION ASSET MANAGEMENT PLAN Rhode Island Department of Transportation*. Retrieved from http://www.dot.ri.gov/documents/RhodeWorks/RIDOT_TAMP_2019.pdf

Roads&Bridges. (2014, June). *TRAFFIC MANAGEMENT: Georgia DOT contemplating drones for traffic control | Roads & Bridges.* Retrieved from https://www.roadsbridges.com/traffic-management-georgia-dot-contemplating-drones-traffic-control

Rupprecht Law P.A. (2017a, May 8). Maine Drone Laws from Attorney & Pilot -. Retrieved September 13, 2019, from https://jrupprechtlaw.com/maine-drone-laws/

Rupprecht Law P.A. (2017b, May 8). Massachusetts Drone Laws from Attorney & Pilot -. Retrieved September 13, 2019, from https://jrupprechtlaw.com/massachusetts-drone-laws/

Rupprecht Law P.A. (2017c, May 10). New Hampshire Drone Laws from Attorney & Pilot -. Retrieved September 13, 2019, from https://jrupprechtlaw.com/new-hampshire-drone-laws/

Rupprecht Law P.A. (2017d, May 15). Rhode Island Drone Laws from Attorney & Pilot -. Retrieved September 13, 2019, from https://jrupprechtlaw.com/rhode-island-drone-laws/

Rupprecht Law P.A. (2017e, July 1). Connecticut Drone Laws from Attorney & Pilot -. Retrieved September 13, 2019, from https://jrupprechtlaw.com/connecticut-drone-laws/

Rupprecht Law P.A. (2019, July 18). Free Part 107 Test Study Guide For FAA Remote Pilot Airmen Certificate (Updated 2019) -. Retrieved August 5, 2019, from https://jrupprechtlaw.com/part-107-test-study-guide/

Smith, M. (2011, April). Flying drone peers into Japan's damaged reactors. *CNN*. Retrieved from http://www.cnn.com/2011/WORLD/asiapcf/04/10/japan.nuclear.reactors/index.html

Snyder, K., Zajkowski, T., & Divakaran, D. (2016). *Unmanned Aircraft Systems (UAS) Operations Support*. Retrieved from North Carolina State University, Raleigh, NC website: https://connect.ncdot.gov/resources/Aviation%20Resources%20Documents/NCDOT%20Final%20Report%2057808%20final.pdf

State of Vermont. (n.d.). Vermont Laws. Retrieved September 13, 2019, from https://legislature.vermont.gov/statutes/fullchapter/20/205

Stevens Jr., C. R., & Blackstock, T. (2017). *Demonstration of Unmanned Aircraft Systems Use for Traffic Incident Management (UAS-TIM) Final Report*. Retrieved from Texas A&M Transportation Institute website: https://static.tti.tamu.edu/tti.tamu.edu/documents/PRC-17-69-F.pdf

Sullivan, M. (2017, June). *Drone Implementation Within the DRBA and RITBA Inspection Programs*. Presented at the International Bridge Conference 2017, National Harbor, MD.

UAV Coach. (2019a). Drone Laws in Connecticut (2019). Retrieved August 13, 2019, from UAV Coach website: https://uavcoach.com/drone-laws-connecticut/

UAV Coach. (2019b). Drone Laws in Rhode Island (2019). Retrieved August 16, 2019, from UAV Coach website: https://uavcoach.com/drone-laws-rhode-island/

Utah Department of Transportation. (2017, March 22). *Unmanned Aerial Systems: Policies and Procedures*. Retrieved from https://www.udot.utah.gov/main/uconowner.gf?n=33805627207740213

University of Idaho. (2016, July). UI, INL and Idaho Companies Partner to Expand Unmanned Aerial Systems Capabilities. Retrieved August 5, 2019, from https://www.uidaho.edu/news/archive/news-releases/2016-july/071416-drones

Vermont Agency of Transportation. (2018). *Vermont Long-Range Transportation Plan*. Retrieved from https://vtrans.vermont.gov/sites/aot/files/planning/documents/planning/2040_LRTP_%20Final.pdf

Vermont Agency of Transportation. (2019). *FY19 Transportation Program*. Retrieved from https://vtrans.vermont.gov/sites/aot/files/portal/documents/aboutus/capprog/19a/FY19TransportationProgram.pdf

Vermont Agency of Transportation. (2019, January). *VERMONT AGENCY OF TRANSPORTATION 2019 FACT BOOK and Annual Report*. Retrieved from https://vtrans.vermont.gov/sites/aot/files/AOTFactBook2019web.pdf

Virginia Department of Transportation. (2019, January). *UAS Operations Manual: Draft*.

Viglienzoni, C. (2019, June). UVM researchers make key use of drones. *Wcax.Com*. Retrieved from https://www.wcax.com/content/news/UVM-Spatial-Analysis-Lab-makes-key-use-of-drones--511795302.html

Xiao, Y., Kamat, V. R., & Lee, S. (2012). Monitoring Excavation Slope Stability Using Drones. *Construction Research Congress 2018*, 169–179.