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INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Investigation of Strategic Deployment Opportunities for Unmanned Aerial Systems (UAS) at INDOT

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16. Abstract

Unmanned aerial systems (UAS) are increasingly used for a variety of applications related to INDOT's mission including bridge inspection, traffic management, incident response, construction and roadway mapping. UAS have the potential to reduce costs and increase capabilities. Other state DOTs and transportation agencies have deployed UAS for an increasing number of applications due to technology advances that provide increased capabilities and lower costs, resulting from regulatory changes that simplified operations for small UAS under 55 pounds (aka, sUAS).

This document provides an overview of UAS applications that may be appropriate for INDOT, as well as a description of the regulations that affect UAS operation as described in 14 CFR Part 107. The potential applications were prioritized using Quality Function Deployment (QFD), a methodology used in the aerospace industry that clearly communicates qualitative and ambiguous information with a transparent framework for decision making. The factors considered included technical feasibility, ease of adoption and stakeholder acceptance, activities underway at INDOT, and contribution to INDOT mission and goals. Dozens of interviews with INDOT personnel and stakeholders were held to get an accurate and varied perspective of potential for UAVs at INDOT.

The initial prioritization was completed in early 2019 and identified three key areas: UAS for bridge inspection safety as a part of regular operations, UAS for construction with deliverables provided via construction contracts, and UAS for emergency management. Descriptions of current practices and opportunities for INDOT are provided for each of these applications. An estimate of the benefits and costs is identified, based on findings from other agencies as well as projections for INDOT. A benefit cost analysis for the application of UAS for bridge inspection safety suggests a benefit cost over one for the analysis period.

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EXECUTIVE SUMMARY

Introduction

Unmanned aerial systems (UAS) are increasingly used for a variety of applications related to the mission of the Indiana Department of Transportation (INDOT), including bridge inspection, traffic management, incident response, construction, and roadway mapping. UAS have the potential to reduce costs and increase capabilities. Other state DOTs and transportation agencies have deployed UAS for an increasing number of applications due to technological advances that provide increased capabilities and lower costs. These advances reflected the opportunity for increased operations that were enabled by regulatory changes that simplified operations for small UAS under 55 lbs (aka, sUAS), as published in Chapter 14 of the Code of Federal Regulations (CFR) in Part 107.

Findings

This document provides an overview of UAS applications that may be appropriate for INDOT, as well as a description of the regulations that affect UAS operation as described in Part 107. The potential applications were prioritized using Quality Function Deployment (QFD), a methodology used in the aerospace industry that clearly communicates qualitative and ambiguous information with a transparent framework for decision-making. The factors considered included technical feasibility, ease of adoption and stakeholder acceptance, activities underway at INDOT, and contribution to INDOT mission and goals. Dozens of interviews with INDOT personnel and stakeholders were held to get a perspective regarding the current uses and potential uses for UAS at INDOT.

Implementation

Three key areas were identified for prioritized implementation by INDOT. (1) UAS for bridge inspection safety, (2) UAS for construction with deliverables provided via construction contracts, and (3) UAS for emergency management. Descriptions of current practices and opportunities for INDOT are provided below for each of these applications.

UAS for Bridge Inspection. Bridge inspections, especially for larger and complex bridges, require temporary work zones, traffic detours, and heavy equipment. UAS can support pre-inspection activities as well as inspection activities and can even provide a perspective that is unavailable when using a bucket truck or the climb team. The use of UAS for bridge inspector safety not only provides a significant benefit by reducing potential incidents, it also provides an excellent way for transportation agencies to integrate UAS into a core activity and develop supporting protocol and policy. As UAS capabilities become familiar to bridge inspectors and other DOT personnel, team members who gain a working knowledge of UAS capabilities will be able to identify additional tasks that could leverage UAS as a tool to enhance safety and efficiency. This report also provides the results of a survey of bridge inspectors, which confirms that many bridge inspectors believe that UAS could be used to support activities during both the pre-inspection and inspection activities.

The usefulness of UAS for INDOT bridge inspection activities was confirmed in January 2020, when a UAS was used in the damage assessment after a bridge hit. The UAS video and images were very useful and complemented the capabilities of the climb team and use of a bucket truck during the assessment. The UAS provided a unique vantage point, and the video will be useful for technical documentation, as well as legal documentation.

UAS for Construction. UAS are being used on construction sites by contractors for many different applications, and constructors are generating valuable data that could be potentially leveraged by INDOT applications. UAS construction applications include construction progress monitoring, safety surveillance, quality assurance, documentation of work zone conditions following an incident, quantity measurement, and communication with stakeholders. The UAS data could be identified as a deliverable item in INDOT construction contracts and may include high definition pictures and video from a standard commercial drone, as well as data such as earthwork quantities moved or stockpile quantities associated with materials contracts. Many constructor UAS applications directly relate to activities that are important for INDOT, such as monitoring construction activities, quality assurance, and managing the safety of the work zone and construction project. In addition to the construction applications that directly overlap with INDOT's mission, data from construction sites could also be utilized for other INDOT applications beyond the construction phase. These applications may include roadside asset inventory (including signs and culverts), as-built documentation, classification of plant species in the right-of-way, and video and images that can be used for communication with the public. The findings include the results of a survey of constructors, which indicates general willingness of constructors to provide drone video and data as a contract deliverable.

UAS for Emergency Management. UAS have been used to support emergency management activities, including emergency preparedness, emergency response, and emergency recovery. UAS provide a valuable tool that can be used safely and in a variety of ways to enhance emergency response, investigate INDOT infrastructure during and after an emergency, and document findings to support local and state requests for federal support through programs such as FEMA. The capability for live feeds from UAS cameras allows UAS to provide data that can support real-time decision making and ensure that response activities are based on current conditions. Video and images from UAS can also be useful for public information during an emergency. UAS have been successfully used by a number of other DOTs and public agencies.

The value of UAS for INDOT is confirmed by the calculation of a benefit cost ratio (B/C) of proposed use for bridge inspection safety. This B/C is estimated based on findings from other agencies tailored to INDOT operations. The resulting benefit cost for UAS to support bridge inspection safety is greater than one, confirming the value of UAS deployment for INDOT's future activities.

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1. BACKGROUND AND PROBLEM STATEMENT

Unmanned aerial systems (UAS) are increasingly used for a variety of applications related to the mission of the Indiana Department of Transportation (INDOT) including bridge inspection, traffic management, incident response, construction and roadway mapping. UAS have the potential to reduce costs and increase capabilities. Other state DOTs and transportation agencies have deployed UAS for an increasing number of applications due to technology advances that provide increased capabilities and lower costs, resulting from regulatory changes that simplified operations for small UAS under 55 lbs (aka, sUAS; in some cases the unmanned aircraft is also referred to as a UAV, the acronym for unmanned aerial vehicle). This study will only focus exclusively on small UAS systems.

The objective of this research project is to provide information to guide INDOT in the strategic deployment of UAS. Supporting research tasks include a review of UAS applications used by other DOTs and transportation agencies, an investigation of UAS deployments in INDOT and by other Indiana agencies that INDOT works with, an explanation of the relevant regulations for UAS operation, development of a framework for prioritizing UAS applications at INDOT, identification of priority UAS applications at INDOT and an investigation of the priority UAS applications identified for strategic deployment by INDOT in the near term.

Investigation of priority UAS applications includes an estimation of the costs associated with UAS acquisition and personnel training, and an estimation of the benefits associated with deployment. Benefits potentially include costs savings for personnel and equipment, time savings for the traveling public, and increased capabilities. The associated cost benefit ratios will be estimated when possible, using current cost data provided by INDOT and savings reported by other agencies.

UAS technology and practices are rapidly evolving. Since the project was conceptualized and contracted, INDOT has made significant advances to support UAS deployment.

2. OVERVIEW OF UAS APPLICATIONS

Simplified operations for the use of UAS was supported by legislation published in Chapter 14 of the Code of Federal Regulations (CFR) under Part 107, commonly referred to as Part 107. The provisions of Part 107 took effect in 2016 and provide operating rules for non-recreational drone use. The simplified rules in Part 107, as well as advancements in drone technology and lower prices, have resulted in a dramatic increase in the market for both recreational and commercial applications. Government agencies have also recognized the potential benefits of UAS and have deployed them at both the local and state level to support a variety of agency activities. The potential for UAS to provide a valuable tool has been reflected by investigations, demonstrations and even deployment as standard practices at other departments of transportation (DOTs) and transportation agencies. Figure 2.1 illustrates the trajectory of growth for UAS equipment by both government and private entities.

2.1 UAS Applications

There are a number of UAS applications that have been documented in scholarly literature, the media, and in UAV consultant reports and websites. Public agencies have incorporated drones into their activities for a wide variety of applications, from emergency response and disaster management to vegetation management (e.g., to assess invasive species and to identify illegally grown marijuana), and construction and infrastructure management (e.g., bridge inspections and construction inspections).

For over a decade, drones have been proposed as a means to provide rapid and accurate information to first responders, and as a tool to provide real-time visual confirmation to the wide variety of stakeholders who participate in emergency response activities (Ameri et al., 2009). Although regulation historically limited the utilization of drones in emergencies (Karpowicz, 2016), the publication of Part 107 in 2016 significantly reduced regulatory constraints. Used properly, drones are a valuable tool that may provide documentation of events, enhance situational awareness, allow distant experts to provide technical assistance in real-time, facilitate communications and the collection of data, and reduce injuries and increase safety during both regular operations and emergencies.

Drones are used for a variety of tasks to support construction and infrastructure management, including surveying and pre-construction activities (e.g., Light ranging and detection (LiDAR), 2D and 3D mapping and imaging), documentation of earthwork quantities, documentation of construction progress and activities, inspections, and aerial photographs and video for communication and project documentation (Gillins et al., 2018; Kim et al., 2016). Drones may also be a useful tool to support quality control and worker safety (Vlieg, 2015). The use of high-resolution photographs and advanced image processing that is facilitated by drone data collection is useful in pavement infrastructure monitoring (Koch et al., 2015; Schnebele et al., 2015). A number of methods have been developed to provide image processing for condition assessment based on high-resolution photos. Condition assessment can also be enhanced by the use of other drone remote sensing technologies such as laser scanners (including LiDAR), ground penetrating radar (GPR), thermal imaging, and acoustics (Schnebele et al., 2015).

State agencies utilize drones to increase their capabilities and, in some cases, lower their costs. Other state agencies that reportedly use drones include State Police, the Department of National Resources, the Department of Fish and Wildlife, and the Department of Ecology;

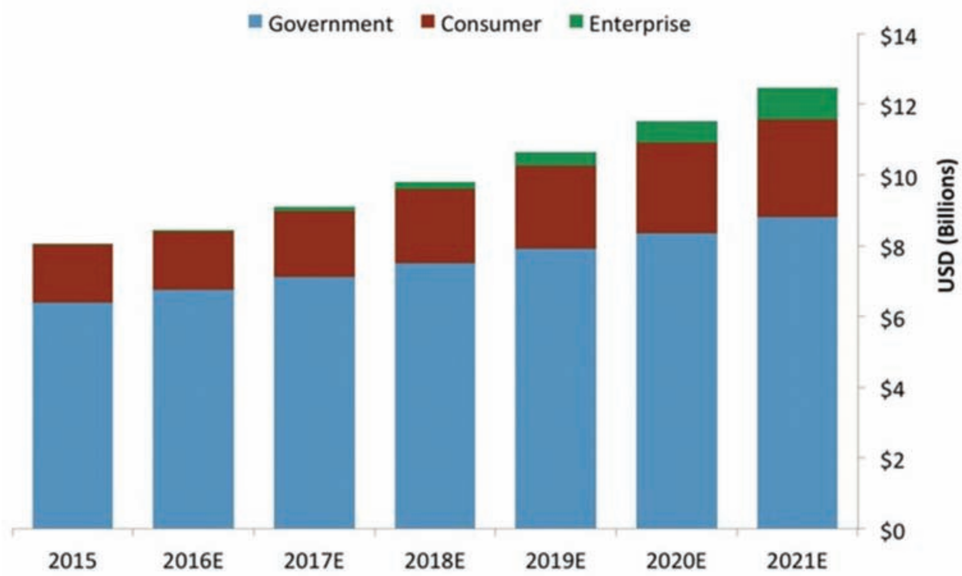


Figure 2.1 Estimated global investment in UAS hardware (Joshi, 2019).

universities are often collaborative partners in the exploration of new drone applications.

There have been a number of surveys of state DOTs in recent years to identify agencies that are actively using drones for research and to conduct regular activities. These surveys generally indicate increasing interest. In March 2016, the American Association of State Highway and Transportation Officials (AASHTO) conducted a survey that found that 17 state DOTs had studied or used drones; Indiana was one of the 17 states due to a feasibility study with the Ohio UAS Center. Another 16 state DOTs were exploring applications, assisting in policy development, or supporting UAS research (Ball, 2016). In August 2016, results of a survey of DOTs by Kansas DOT indicated that 7 had submitted requests for a Certificate of Authorization (COA) exemption for CAA and 7 were considering purchasing a UAS once regulations allowed for commercial use when Part 107 became effective on August 29, 2016 (McGuire et al., 2016). By March 2018, AASHTO reported the results of another survey, which indicated that twenty state DOTs were using drones for daily operations, and 15 more DOTs (including INDOT) were researching how drones could best be deployed (AASHTO, 2018).

There are a wide range of UAS applications that have been implemented, investigated and explored. Table 2.1 provides a comprehensive list of all the UAS applications that were found, as well as a list of the UAS equipment that is frequently used. Some applications, such as bridge inspections, have been studied for many years by numerous agencies. Michigan DOT has worked with Michigan Tech for more than four years, and has found drones to be a safe, reliable and cost-effective tool (AASHTO, 2018). North Carolina DOT has worked with the State Highway Patrol to deploy drones for incident management, as well as to reduce crash reconstruction times. Using drones can reduce the time to less than one fourth of the time required by traditional reconstruction methods (25 minutes with a drone vs. 111 minutes with traditional methods). This time reduction allows the road to open sooner, which can save approximately $5,000 per interstate crash, considering only user delay and the associated lost productivity (AASHTO, 2018). DOTs that use drones for regular activities report the following top five applications:

- photos and videos (all agencies use a drone for this),
- mapping and surveying (70%),
- public education and outreach (60%),
- bridge inspections (50%), and
- emergency response (40%).

Looking toward future applications, the majority of current and planned UAS activities reflect the following categories (Plotnikov et al., 2018):

- asset management,
- construction,
- disaster management,
- environmental monitoring,
- infrastructure inspection,
- safety,
- surveillance, and
- traffic operations.

New approaches to the applications in Table 2.1 are being reported. Pedestrian and bike studies include drones for pedestrian observation (Park & Ewing, 2019), as well as a crash warning system for the bike lane at intersections with connected vehicle technology (Wu et al., 2019). UAV for pavement inspections includes monitoring pavements on expansive soils (Congress & Puppala, 2019). UAV for traffic monitoring includes the detection of non-recurrent congestion (Yahia et al., 2019) and wrong-way entries onto the interstate (Jalayer et al., 2019). UAV for environmental compliance includes not

TABLE 2.1
UAS Applications and Equipment

Example UAS Applications	Example UAS Equipment
Advertising and public information	*Hardware*
Agricultural monitoring	Video camera, including optical (zoom) and RGB (red green blue, enhanced color capabilities)
Aerial imaging	IR (thermographic or heat sensing)
Airport obstruction surveys	LiDAR
Airport perimeter control	Inertial platform (e.g., gimbals)
Avalanche control and earth slides	GNSS (including GPS and other satellite systems)
Bridge inspection (roadway, rail and pedestrian)	Lights
Building inspections	Control stations (e.g., tablet)
Construction inspection	Wind measuring equipment
Crash investigation	Software
Confined space inspection	Pix4D (post-processing)
Corridor analysis (AR)	Drone Deploy (drone mapping)
Culvert inspection	Drone Complier (preflight)
Delivery	ProCore
Disposal area inspections	LANNC applications (airspace authorization)
Dam and dyke inspection	Aeronyde
Emergency management	Airbus
Environmental compliance (including wetlands)	Airmap
First responder information	AiRXOS
Fire fighting	Altitude Angel
High mast pole inspections	Converge
Heritage inspections (monuments and statues)	DJI
Law enforcement (fugitive and missing person tracking)	Harris Corporation
Media relations	Kittyhawk
MSE wall inspections	Project Wing
Pavement inspections	Skyward
Pipeline inspections	Thales Group
Railroad inspections	UASidekick
Rockfall inspections	Unifly
ROW studies	B4UFLY
Pedestrian and bike studies (including ADA audits)	Skyvector (online aeronautical charts)
Sinkhole monitoring	
Surveying and photogrammetry	
Stockpile measurement	
Structural inspections	
Traffic monitoring	
Tower inspection	
Unpaved road monitoring	
Waterway inspections	
Work zone audits and documentation	
Wildlife surveys	

only wetlands monitoring, but also roadside air quality monitoring (Li et al., 2019).

There is a variety of equipment, both hardware and software, being used to support UAS deployment. Basic equipment includes the aircraft (aka vehicle), the control station, the communications, and cameras or sensors required for the project. Other important equipment that is necessary includes the computer and software to download, process and save the data (including imagery) collected, as well as pre-flight planning software. Pre-flight software includes programs such as Low Altitude Authorization and Notification Capability (LAANC), which provides real-time authorization for airspace use.

It is important that agencies consider the system capabilities and requirements, rather than merely focusing on hardware and components. Georgia DOT has identified the following UAS system requirements for UAS:

- sense and avoid,
- waypoint navigation,
- kinematic constraint of flight operation,
- high precision navigation,
- unattended deployment and return,
- simultaneous location and mapping (slam),
- advanced data-link and networking,
- sensor data abstraction and reduction, and
- vision based data extraction.

These capabilities would typically be purchased as part of the UAS, rather than as add-on components or capabilities. One issue that DOTs are facing as applications increase, different applications may be best served by different types of UAS. The resulting data and systems are typically not interchangeable or compatible and do not use a common framework for data or images. Long term, data management will be an increasing issue, and no public agency has fully addressed this issue or identified best practices. Collins Engineering and MnDOT are working with Intel to begin to address the need for data management for UAS in the future.

Just as applications and equipment are evolving, state DOTs are also creating operating procedures and supporting policies that include the following components (Plotnikov et al., 2018):

- procedure for an agency business decision regarding a proposed UAS deployment,
- procedure for airspace use authorization,
- operator qualifications,
- flight planning process, responsibility, and oversight,
- pre-flight, flight and prost-flight procedures (includes checklists, safety review, maintenance logs and data management), and
- emergency/accident procedures.

Some of these policy components may become less burdensome, as the sector advances and tools such as LAANC simplify airspace authorization and other activities. A study of published state policies found that only four states had comprehensive UAV policies (Florida, Georgia, Minnesota and North Carolina). Approximately half had a UAS webpage and referenced FAA regulations (Bausman et al., 2019). A detailed table of topics addressed by state policies is included in the Appendix.

The importance of policy is echoed by the recent *National Cooperative Highway Research Program (NCHRP) Domestic Scan 17-01*, which identified the following seven themes: (1) executive support, (2) organizational structure, (3) policy and regulation, (4) safety and risk management, (5) training and crew qualifications, (6) public relations, and (7) application and operation (Banks et al., 2018). In terms of application and operation, the scan program identified the following characteristics of successful programs (Banks et al., 2018):

- started small (without a large investment) and expanded with success;
- justified UAS based on benefits such as increased safety, reduced liability, cost savings, increased productivity, improved service or end product, environmental protection, and reduced impact on traveling public;
- followed standard operating procedures;
- leveraged UAS assets across disciplines and shared resources throughout the state; and
- developed workflow processes for data collection, storage, and use, as well as processes for the development of new applications and for the use of data collected to assure it is used for multiple purposes.

Video is the most common equipment used and ranges from GoPro cameras to advanced optical or RGB cameras (RGB refers to Red-Green-Blue colors which are used for the sensing, representation and display of colors in electronic formats). Optical cameras provide high resolution images from a distance due to their zoom lenses, while RGB cameras are typically capable of providing better images in low light conditions.

UAS include the control station and the vehicle (aircraft). There are a variety of aircraft, as shown in Table 2.2. Multirotors include quadcopters, hexacopters and octocopters. They have similar flight characteristics to manned helicopters.

Quadcopters are the most common UAV, which has resulted in lower prices and a wide availability of vendors and off-the-shelf equipment. Quadcopters and other multirotors provide vertical take-off and landing (VTOL) capabilities, hover capabilities, and precision flight paths, which combined with advanced software, allow automated flight patterns that facilitate applications such as 3D mapping.

Hexacopters and octocopters are multirotors with more six and eight propellers. More propellers provide greater stability in harsh conditions, the capability to carry heavier payloads, greater stability, and the ability to function if a propeller is lost. Costs increase with the increasing capabilities of these larger UAV.

Fixed wing UAV are more like traditional manned aircraft in terms of their maneuverability and flight characteristics. Fixed wing UAV may "take off" from a runway or stretch of pavement or be launched by a launching station or manually (thrown by a person). Fixed wing UAV have substantially longer flight times and flight distances and may be an appropriate choice when it is necessary to traverse miles of roadway, perimeter, railroad or pipeline.

In some cases, such as for traffic monitoring of a fixed location, multirotor UAV may be tethered. This allows a continuous power supply and data download capability. There are still situations in which interpretation of drone policy can vary. At the TRB UAS Subcommittee meeting on January 15, 2019, in Washington DC, one agency reported that their FAA contact said that a tethered drone operating 150 ft or lower is not considered a drone and does not require compliance with Part 107. When the research team reached out to FAA to confirm this interpretation, it was refuted.

TABLE 2.2
Types of UAV

UAV	Description or Photo	Capabilities and Limitations
Multirotor	Includes quadcopter, hexacopter and octocopter.	Vertical take-off and landing (VTOL). Hover capabilities. Precision flight and routes.
Quadcopter	 DJI Mavic 2 Pro (DJI, n.d.a).	Inexpensive. Largest market allows off-the-shelf equipment.
Quadcopter with safety system	 ParaZero Drone Safety System (Parazero, n.d.).	Drone with ParaZero SafeAir parachute recovery system has been approved for flight over people for selected agencies that are part of the federal UAS Integration Pilot Program. Parachute is ASTM-compliant and allows. operations under this waiver (Lillian, 2019).
Confined space drone	 Flyability Elios 2 (Flyability, n.d.).	Small caged drone designed for inspections. Can be used in confined spaces. Collision tolerant. Compatible with thermal camera and RGB video. Camera can tilt 180 degrees. LED lighting (dustproof).
Hexacopter	 Yuneec Typhoon H3 (Yuneec, n.d.).	Capable of higher altitude and greater speed than quadcopter. Can maintain control if a rotor is lost or damaged. Can carry heavier payloads than quadcopter. More expensive than quadcopter.
Multirotor—octocopter	 Freefly ALTA 8 (Freefly Systems, n.d.).	Can maintain control if one or two rotors are lost or damaged. Increased capabilities in wind and harsh conditions. Can carry heavier payloads than hexacopter or quadcopter. More expensive than quadcopter or hexacopter.
Fixed wing	 senseFly eBee Classic (senseFly, n.d.).	Capable of greater distances than multirotors.

TABLE 2.2
(Continued)

UAV	Description or Photo	Capabilities and Limitations
Hybrid	 DeltaQuad Pro (Vertical Technologies, n.d.).	Benefits of both multirotor (e.g., VTOL and precise flight paths) and fixed wing (e.g., able to fly greater distances than multirotor).
Nano-UAV	 Black Hornet (FLIR, 2017).	Nano-UAV for surveillance, reconnaissance and defense. Flight time up to 25 minutes. Captures video and still images and IR.
Multirotor—quadcopter	 Airbus advanced inspection drone (Airbus, 2018).	Airbus and Testia (subsidiary for non-destructive testing) developed this drone. Designed for use in a hangar for aircraft inspection for fast and accurate inspections. Follows predefined inspection path. Takes pictures where are then transferred to PC database for detailed analysis. Facilitates identification and measurement of visual damage compared to digital aircraft. Inspection report automatically generated.

3. REGULATIONS

The Federal Aviation Administration (FAA) has the exclusive authority to regulate aircraft operations, aviation safety, the navigable airspace, and air traffic control. Since drones operate in the navigable airspace, the FAA has the authority to regulate drones.

3.1 Part 107

Drone operation is governed by federal law which is defined in Part 107 of Chapter 14 in the *Code of Federal regulations*, aka 14 CFR Part 107. Part 107 became effective on August 29, 2016. These rules apply to drones (also called small unmanned aerial systems or sUAS) that are under 55 lbs. The 55 lb limit refers to the drone and all "payload," which refers to the equipment or other supplies carried by the drone.

Part 107 requires that all drone use for business or commercial purposes comply with rules for the remote pilot, operation, and limits on operation (there are additional rules but these are the ones typically of primary interest). Some of the most important rules are summarized in Table 3.1 and discussed below.

The remote pilot, also referred to the as the remote pilot in command, must have an FAA Remote Pilot Certificate. The cost of the exam is $150, and the certificate is good for two years. The remote pilot is responsible for the safe operation of the drone and compliance with all FAA rules. The remote pilot must be on-site during operation but may supervise someone else to serve as the operator of the flight controls, as well as a visual observer and keep the drone in visual line of sight (VLOS) throughout operation. Visual line of sight refers to the capability to see the drone without anything other than corrective lenses. Each drone operator and visual observer may only be responsible for one drone at a time.

In addition to maintaining VLOS, the drone must be flown during daylight. If the drone has anti-collision lighting, flight may be extended into civil twilight, which is 30 minutes before sunrise or 30 minutes after sunset. The drone must fly at or below 400′ above ground level, although it can fly higher near a tall structure. If the drone is flying within a 400′ radius of a structure, it must fly at or below 400′ above top of structure.

Operating rules also include numerous limits or prohibitions. To protect the safety of aircraft, drones must yield to aircraft (including airplanes, helicopters and balloons) and respect airspace limits. Airspace limits include restrictions from some airspace near airports (e.g., the approach path for landing airplanes), and requirements for permission from air traffic control for flights in airspace near airports designated as Class B, C, D, or E airspace. The restrictions associated with each class of airspace are shown in Figure 3.1.

To protect the safety of people, drones must not fly over them, unless they are participating in the operation or are under the cover of a structure or a stationary vehicle. Drones must not be operated from a moving vehicle, boat, or aircraft unless the activities are being conducted in a sparsely populated area.

Other safety rules require that the pilot not have any medical conditions that would compromise the safety of the flight, must not operate the drone recklessly, carry hazardous materials, or fly in adverse weather conditions, including when visibility is less than 3 miles from the control station.

The remote pilot must report any accidents that cause more than $500 damage (not including damage to the drone) or in which there is a serious injury. This is important not only for regulatory compliance, but also because the remote pilot license under Part 107 could be revoked if an accident report is not filed as required. Additional information about accident reporting is included in the appendix.

Part 107 also provides rules for the UAV or drone. The drone must be registered with the FAA; registration is $5, is valid for three years, and can be done online. The drone must be labeled with the registration number and must be less than 55 lbs. This includes the weight of both the drone and payload. The remote pilot is responsible for conducting a preflight check, which includes a visual check, operational check, and check of the communications link and other safety-pertinent systems. Unlike manned aircraft, the FAA does not provide or require a certificate of airworthiness for the drone. However, the remote pilot must make the drone available to the FAA for inspection or testing upon request and must be prepared to provide any associated records that are required to be kept under the rule.

TABLE 3.1
Selected Rules Under Part 107

Pilot	Must have an *FAA Remote Pilot Certificate*. Must *be on-site* during operation. May *supervise operator* of drone flight controls. May *utilize a visual observer.*
Operating rules	Must be in *visual line of sight (VLOS)*. Must fly during *daylight*. Must fly at or *below 400′*. Must *yield to manned aircraft.* Must fly at or *below 100 mph.* Must *report accidents to FAA.*
Operating prohibitions	Must *NOT fly in restricted airspace*. Must *NOT fly over people.* Must *NOT be operated from a moving vehicle.* Must *NOT operate more than one drone per pilot* or visual observer. Must *NOT carry hazardous materials.* Must *NOT be careless or reckless.* Must *NOT fly during reduced visibility.*
Drone or UAV	Must be *registered with FAA*. Must be *less than 55 lbs.* Must undergo a *preflight check.*

3.2 Operational Waivers

Operational waivers provide exemptions to rules to allow flight over moving vehicles, beyond visual line of sight (BVLOS), over people, from a moving vehicle, or other requirements of Part 107. It is possible to obtain a waiver for these rules by requesting them from the FAA.

Government Entities, including state agencies, local agencies and law enforcement have two options for flying UAS: (1) Follow all rules under *14 CFR Part 107*, or (2) Obtain a blanket public *Certificate of Waiver or Authorization (COA)*. COAs are valid for two years and can be renewed.

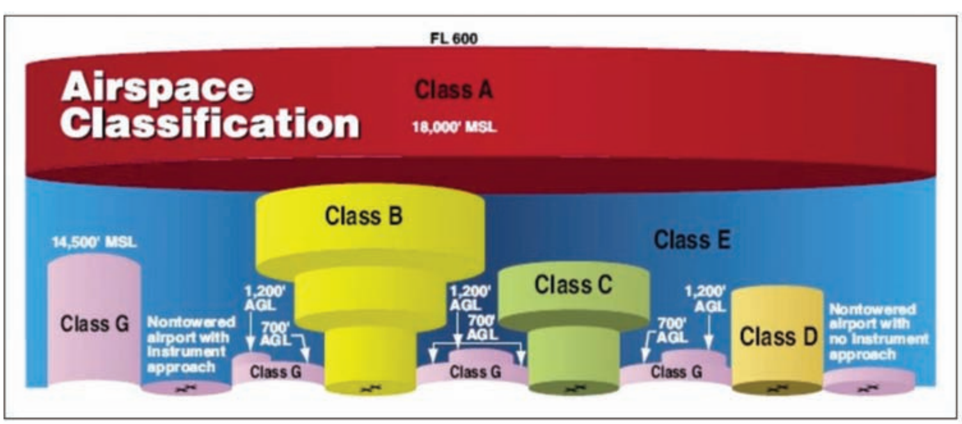


Figure 3.1 FAA airspace classifications (FAA, n.d.).

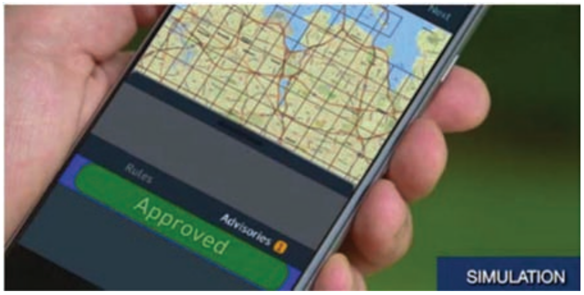


Figure 3.2 LAANC provides convenient and fast authorization (Kmia, 2018).

Emergency waivers can also be obtained from FAA, and approval is usually expedited.

Prior to Part 107, some organizations operated drones under a Section 333 exemption; these organizations can continue to do so until the exemption expires. Generally, FAA will not issue renewals for these exemptions.

In many cases, airspace waivers can be granted quickly through the *Low Altitude Authorization and Notification Capability (LAANC)* when the proposed flight is in controlled airspace, but only at altitudes considered safe for nearby airports. LANNC was beta tested throughout 2018 and can be used at the following airports in Indiana: Indianapolis International (IND), Evansville (EVV), Terre Haute (HUF), South Bend (SBN), Fort Wayne (FWA) and Purdue (LAF). LAANC provides convenient and fast authorization through a cell phone app or laptop, as shown in Figure 3.2.

The rapid growth of the UAS sector, the rapid advancements in UAS technologies and the relative immaturity of the regulatory framework suggest the potential for a dynamic environment. This is shown by the recent addition of the LAANC system, which provides operational waivers for airspace in real-time. There is some expectation that the framework for other waivers and the associated limits under Part 107 may change in the near future.

3.3 State and Local Laws

There are some state laws in Indiana that address drones, but none of these would be expected to hinder operations by INDOT.

- In 2014, a law was passed that addresses the use of drones for law enforcement and for surveillance of private property (HB 1009).
- In 2016, laws were passed that allowed drones to be used to take video and photos to document the site of a traffic crash (HB 1013) and to prohibit the use of drones to scout game during hunting season (HB 1246).
- In 2017, a law was passed to make it a crime for a sex offender to use a drone to photograph, contact, or track someone. It creates an offense for remote aerial harassment. This law also makes it a crime to use a drone to obstruct or interfere with public safety officials carrying out their duties (SB 299).
- In 2018, a law was passed to prohibit drones in state parks and other recreational areas that are property owned by the Indiana Department of Natural Resources (DNR). However, the DNR may grant exceptions for filming or other approved purposes (IAC 312-2-8 (i)).

Local laws and ordinances to restrict drones have been struck down since they are preempted by the federal law which gives FAA the responsibility to regulate airspace (e.g., Singer v. City of Newton as described in *Harvard Law Review*). The FAA provides context, clarifying that they are responsible for regulating all aircraft operations (including unmanned aerial vehicles aka drones), flight paths and airspace. State and local powers, however, do allow regulation of local police power including land use planning, zoning, privacy and law enforcement. Local agencies and cities can regulate the location of aircraft landing sites but are not permitted to regulate the operation of aircraft (FAA, 2018a).

4. INDOT ACTIVITIES AND INTERESTS

There are a number of activities underway and planned at INDOT and partner agencies such as JTRP. The research team had discussions with a number of INDOT and JTRP personnel to learn more about these activities. Discussions were held with personnel from district offices (e.g., Crawfordville and Seymour), and the central office (e.g., bridges, aerial imaging, safety, construction, logistics and environmental monitoring). INDOT groups, researchers, and partner agencies that participated in discussions are listed below:

INDOT

- Bridge Group: three interviews including personnel from Central and District Offices
- Aerial Imaging: two interviews
- Aviation: two interviews
- INDOT committee to support UAS operating procedures and UAS purchase
- Logistics, Statewide perspective
- Stockpile monitoring (aggregate and salt) and facilities management: two District Offices
- Maintenance perspective: JTRP research focus group for Highway Maintenance Operations (MOP)
- Traffic monitoring (roundabout queue near exit ramp) at Seymour District
- Central Office
  - Safety
  - Emergency Management
  - Construction: two people
- Environmental Services: two people

INDOT Partners and External Stakeholders

- INDOT construction contractors
  - Milestone
  - Reith-Riley
  - E&B Paving
  - Merritt
- Law Enforcement
  - County Sheriff's office

- JTRP workshops for incident management: two people
- JTRP pooled fund study for UAS
- Local agency perspective
  - County engineer and former consultant for county bridge inspections
- Rail
  - BNSF
- Consultant Perspective
  - Collins Engineers, Inc.
  - Woolpert
  - Butler Fairman and Seifert
  - USI

Other Department of Transportations

- Minnesota Department of Transportation

Comments about current and potential uses for UAS are summarized below. The individual meetings have been an important source of information in the development and refinement of the candidate application list and the subsequent prioritization of candidate applications. The research team has made every effort to assure that the results of these discussions foster communication activity within INDOT by sharing information with various INDOT stakeholders on the wide range of INDOT interests, activities and personnel involved with UAS development.

Bridge Inspection

- UAS could support bridge inspections by providing a pre-inspection to ensure it is safe for inspectors to go onto the bridge.
- Similarly, drone video may provide footage that would be helpful for bridge inspections, reducing the need for the snooper truck and associated lane closures.
- After damage caused by a storm, UAS could be used for bridge inspection, including under the bridge where a drone could investigate the damage and provide a detailed view.
- UAS can be used in assessment after a bridge hit. Video and images captured by UAS may provide a unique perspective that cannot be obtained from the climb team or the bucket truck. The images collected by UAS may assess and confirm damage and may be helpful in any litigation related to the bridge hit.
- The information gathered via UAS for bridges during flooding could be useful to identify routes that should be open or closed.
- UAS provides information that would be useful when coordinating with neighboring states. When the Wildcat Bridge was out and traffic was re-routed, INDOT let adjacent states know about the issues so traffic could take alternate routes.
- UAS could be used for bridge inspections after an earthquake since inspectors should not be under the bridge during aftershock periods.
- UAS would have been helpful during the I-65 Wildcat Bridge closure. Inspectors could have flown a drone under the bridge if there was concern about collapse.
- For rail bridges, UAS are used to look at joints, track condition, and rust. UAS operations are often performed alongside the bridge, since it is difficult to fly under the bridge because of communication issues and loss of global positioning system (GPS) signal under the bridge. Bridge inspectors and structural engineers use UAS information to plan upcoming on-site bridge inspections.

Confined Space Inspection

- UAS may be appropriate for confined space inspections. UAS would be specially outfitted (collision tolerant) for the task, would need to operate without GPS, and have lighting capabilities.

Mechanically Stabilized Earth (MSE) Wall Inspection

- It has been suggested that INDOT should use UAS to monitor MSE (mechanically stabilized earth) walls for movement. This could be accomplished by flying next to the wall and no more than 100 feet to 200 feet above the wall, which may be a good application for a tethered drone.

Aviation Obstructions and Airport Support

- UAS could be implemented for airport obstacle analysis to assure that the airport approach (for takeoff and initial climb out) is free of obstacles such as trees.
- Check visibility of lighted windsocks (wind cones).

Stockpile Monitoring

- UAS can be used to quickly determine the volume of a stockpile (salt, aggregate, soil, etc.).
- The process for UAS stockpile measurement is more efficient and safer than the traditional manual process.
- The current process for stockpile measuring is more time consuming, requiring two workers and a total of 20 man-hours to survey one stockpile.
- UAS will do in a day what would take two weeks and two employees to complete for stockpile monitoring.
- UAS can provide accuracy within a couple of percents (2% to 3%), compared to traditional methods (one respondent claimed 1% accuracy). Current "off the shelf" equipment can provide this accuracy.
- UAS could provide a baseline measurement for all stockpiles on a quarterly measurement and would help support inventory control and assist with audits.
- An accuracy of less than 5% would be sufficient for inventory control purposes since current estimates may be off by 100%.

Construction Activities

- UAS could be used for aerial imaging of future large construction projects.
- UAS could be used to document work zone traffic set-up for liability issues. In this case, a UAS would collect photo and/or video documentation of the work zone any time an accident occurs.
- UAS could be used for a survey before the final construction payment, which will be less expensive than sending someone out in traffic to conduct field measurements; the drone is also safer and reduces the need for traffic control.
- UAS could be used to check temporary traffic controls used for construction and maintenance.

Public Relations and Public Information

- UAS could be used to support public communication (I-69 video given as an example).

- UAS could be used to support marketing and recruitment efforts.

Traffic Monitoring

- UAS could be used to support accident indent response and re-routing traffic.
- UAS could be used at intersections of state roads and county roads for issues such as determination of line of site.

Pavement Inspections

- UAS could be used to provide IRI for new pavements.

Landslide Monitoring

- UAS could support monitoring and corrective action for earth slides (landslides) in Southern Indiana.

Facility Management (Buildings)

- UAS could be used to support facility review to ensure INDOT employee safety. For example, INDOT employees inspect and perform maintenance on roofs. One district noted over 200+ buildings in their district *(which suggests there could be over a thousand buildings in all of the districts)*.
- UAS could be used to check building rooftops and inspect facilities after storms. These inspections may include video and FLIR (infrared) which could find roof leaks using heat signatures. Information gathered via UAS could also allow INDOT to prioritize where repairs are needed based on heat loss.

Asset Management (includes INDOT Signs, Culverts, etc.)

- UAS could be used to confirm correct sign placement.
- UAS could be used to inspect culverts.
- UAS could be used to identify all assets along a corridor, or to film a roadway or corridor, and INDOT personnel could use the video to obtain information and data they need rather than making a site visit.
- UAS could be used for asset management; this was noted as the second major application after bridge inspection.

Vegetation Management

- UAS could be used to identify and support vegetation management, including invasive species identification and management.

Incident Management and Documentation of Scene

- UAS could be used to support incident management for traffic incidents much like emergency management (as noted below).
- UAS are currently used to document the crash scene in Tippecanoe County. Both law enforcement and construction contractors confirmed that they use UAS to document crash scenes as well as the work site and traffic control at the scene of an accident.

Environmental Monitoring

- UAS could be used to support environmental management such as determining watershed areas and places where damming issues are occurring.

Americans with Disabilities Act (ADA) Compliance

- No comments from INDOT personnel or other stakeholders.

Park and Ride Lot Survey

- No comments from INDOT personnel or other stakeholders.

Aerial Imaging

- UAS could support aerial imaging traditionally done by fixed wing aircraft.
- UAS could be used for photogrammetry and surveying. This might include topography for a corridor project or large reconstruction project.
- It would make sense to work with the GIS group to help support/develop projects for construction.
- One of the restrictions for UAS is that mapping requires very sophisticated sensors, which are too expensive for INDOT (e.g., the sensors needed cost hundreds of thousands of dollars).
- Flying UAS in the right-of-way is not adequate for INDOT needs in some cases. It would be necessary to fly over the lanes of travel, but this is not allowed under Part 107 since it would require flying over moving vehicles.
- In many instances, aerial imaging needs to fly over moving vehicles.

Emergency Management and Disaster Response

- UAS would be useful for responding to major incidents such as a Wabash Valley earthquake.
- UAS can provide live video feed to INDOT's operation center so quicker and better decisions can be made with respect to re-routing traffic as well as the appropriate response in terms of equipment, personnel and capabilities.
- UAS can be helpful not only for major state routes but also for all the lesser state roads.
- Emergency egress routes could be surveyed by UAS; this would be valuable for lesser state roads that are narrow. This would allow live video for the ops center, allowing for better decisions for rerouting traffic.
- UAS can be flown down a state road to see if there is clearance with respect to the building fronts after a storm.
- UAS will help shorten emergency response time frame.
- UAS would work well for mitigation and in the event of an emergency. For example, when the I-65 Wildcat Bridge went out, there was a sagging bridge and there was concern about collapse. Ideally, you would take a field unit out and send live view video to provide information. This would help in terms of response time.
- UAS will provide better information than verbal reports, which are currently used when there is a road closure.
- The California fires have shown the magnitude and complexity of response activities, as well as the important role that UAS can play.
- Incident command (formal position in the Incident Command Structure) needs to know what is out there in terms data and information; UAS can provide information to support important decisions.

- It would be appropriate to establish priority aerial routes in an emergency. UAS would need to avoid these routes; UAS also needs to stay out of FEMA supply routes.

INDOT Implementation in Emergency Management

- Personnel in the INDOT Office of Aviation will manage all the FAA requirements in an emergency.
- INDOT aviation should own drones or have a responsibility for drones since they have a close connection with FAA and understand FAA rules and regulations.
  - Aviation Team identifies priority air routes after earthquake or flooding.
  - They currently use rental aircraft on major events.
- INDOT is the Aviation Branch Chief for Indiana response during an emergency; INDOT Aviation also supports the aviation needs of the EOC (Emergency Operations Center) and is in charge of all aircraft that are used in support of the disaster response, as well as TRF (temporary flight restrictions), other flight restrictions, or aviation needs.
- A drone used for emergency management would be dual purpose, but in an emergency, the emergency need trumps all other needs.
- When there is not an emergency, the drone used for emergency response could be loaned out to other INDOT divisions, including construction, bridge inspections, etc.

Concerns

- Safety and liability of drone operations is a concern.
- Following the Part 107 rules in all INDOT operations may not meet all of INDOT's needs and may not fully leverage UAS capabilities. It is not clear whether operation under Part 107 will be adequate to do all required tasks (e.g., it will be hard to get the video and data needed without flying over moving vehicles).
- It may not be possible to get the UAS equipment that is needed with the funds INDOT is able and willing to spend.
- Use of UAS in an emergency must be consistent with the responsibilities of INDOT Aviation and anyone operating a UAS must avoid priority aerial routes and FEMA supply routes.

5. PRIORITIZATION OF POTENTIAL APPLICATIONS FOR INDOT

Prioritization of candidate UAS applications considered a number of factors described in greater detail below.

- *Ease of adoption:* Ease of adoption refers to how easily the technology can be deployed, considering physical and financial requirements of the proposed deployment, as well as regulatory, institutional and political considerations.
- *Stakeholder acceptance:* Stakeholder acceptance reflects the organizational and individual support or concerns with the proposed deployment. Affected stakeholders potentially include all organizations and individuals who would be affected by the proposed technology deployment. This would include the people and organizations that use the technology (e.g., INDOT district personnel), interface with the technology, pay for the technology or are affected by its deployment in any other way. Stakeholder acceptance would include both labor and management perspectives.
- *Benefits:* Benefits includes the benefits and costs associated with the proposed technology application. Benefits generally align with activities that support INDOT's mission and goals. Examples include improved operations during regular conditions, improved operations during emergencies, increased safety for the traveling public and INDOT workers, increased mobility, increased efficiency, reduced costs, and applications that communicate (with the public and within INDOT) and support education (including public education) and workforce training.
- *Technical feasibility:* Technical feasibility refers to the practicality and maturity of the proposed technology deployment, including the equipment, machinery, computers, or automation in the context of the airside environment in which it will operate.

5.1 Ease of Adoption and Stakeholder Acceptance

Ease of adoption and stakeholder acceptance are closely related and recognize the potential challenges or support in adopting UAS at INDOT for a given application. Ease of adoption and stakeholder acceptance encompass both individual characteristics, such as whether INDOT workers would use the technology if it were available, and institutional characteristics, such as management support, and support from external organizations including FHWA and FAA.

One of the most broadly used general frameworks of user acceptance is the technology acceptance model (TAM) which states that perceived usefulness and perceived ease of use are the main determinants for an individual's use of a technology (Davis, 1989). Perceived usefulness is whether workers believe the technology will help carry out a task. Perceived ease of use is how much effort is needed to properly use the technology.

The unified theory of acceptance and use of technology (Venkatesh et al., 2003) provide additional context for technology, and recognizes social influence and organizational factors, such as facilitating conditions and whether use is voluntary.

Ease of adoption and stakeholder acceptance would encompass characteristics of both individual users (e.g., maintenance workers), as well as management and the larger organization (INDOT, n.d.), and any partner organizations that may be affected (e.g., emergency responders in the case of an incident, or external partners such as contractors). Relevant considerations may include the attitude of individual users, compatibility of the proposed technology with the task, and organizational influences.

In the context of this study, ease of adoption would encompass regulatory issues such as whether FHWA would accept the use of drones for a bridge inspection, and whether the proposed use of UAS is consistent with Part 107 and other FAA rules.

In the context of this prioritization, assessment of stakeholder acceptance and ease of adoption are based on the discussions with INDOT personnel, which are considered indicative of interest in adopting UAS for the candidate applications. Stakeholder acceptance and ease of adoption are also reflected by activities that have already been initiated by INDOT and partner agencies. Stakeholder acceptance and ease of adoption are reflected in columns 1 and 2 of Table 5.1.

5.2 Benefits

A UAS application may be easy to adopt and technically feasible, but if it does not provide adequate benefits, then there is little value in deployment. The benefits assessed reflect the INDOT mission, values and agencies goals (INDOT, n.d.) described below:

- contributes to the operation of the transportation system during regular operations,
- contributes to the operation of the transportation system during emergency situations,
- increases transportation system safety for the traveling public,
- increases safety for the INDOT workforce, and
- increases mobility for the traveling public.

Other important benefits captured in this analysis include the following:

- improved efficiency,
- provides cost savings, and
- supports communications, education and training.

Improved efficiency, cost savings, and communications with the public and public education are consistent with 2019 Agency Goals to deliver great service and improve construction and maintenance processes and business practices (INDOT, n.d.). Supports communications within INDOT and education and training for INDOT personnel are an important component of the agency goal to develop INDOT's 21st Century Workforce. Benefits are reflected in columns 3 through 10 of Table 5.1.

5.3 Technical Feasibility

The technical feasibility of a candidate application reflects the maturity of the proposed technology in terms of whether it has been demonstrated for that application through investigations, demonstrations, or full deployment into standard practice. The maturity of a technology is often measured by the Technology Readiness Level (TRL), which has been widely used in the defense industry and is determined using a Technology Readiness Assessment (TRA). A TRA examines the following areas: (general) technology readiness, safety concerns, risk criteria, and sustainability. The resulting TRL ranges from 1 to 9, with 1 representing the lowest level of readiness and 9 representing a technology that has been successfully deployed into practice as part of standard operating procedures, as shown in Figure 5.1. If the TRL does not align with the proposed project, then it may be appropriate to shift the proposed implementation concept from a full deployment to a demonstration project, or from a demonstration project to an investigation, or to delay the project until the technology has advanced. Technical feasibility, as ranked based on the TRL, is shown in column 12 of Table 5.1.

Information for each of the candidate applications is shown in Table 5.1. Table 5.1 also includes information about whether INDOT activities in this area are underway (column 1), which as previously mentioned, aligns with the stakeholder acceptance and ease of adoption. In some cases, such as for traffic monitoring, INDOT has done a project with a drone, as indicated by "demo," but the use of a drone for this application is not part of regular operations or standard procedures. In the case of aerial imaging, drones have been purchased and are a regular part of INDOT procedures. For incident management, INDOT is supporting the purchase of drones for the Indiana State Police (ISP), which will facilitate the timely documentation of the accident scene and return to normal operations. It is not clear if the ISP will document the work zone traffic control, which would provide valuable information for INDOT both for liability, as well as continuous improvement, education and training. For emergency management and disaster response, a drone is currently being procured so the activity has been initiated. JTRP projects for 2019 have been identified in research needs statements, but proposals have not yet been written and the projects have not been approved. JTRP research needs have been identified for (1) salt pile monitoring and landslides and (2) bridge inspections.

5.4 Quantifying the Results of the Evaluation into a Score

Due to the conceptual nature of some criteria components, the proposed evaluation is a mix of quantitative and qualitative information. For many UAS applications, the technologies are still evolving and there is a degree of uncertainty associated with their operation, which increases the importance of qualitative information and assessment.

The TRL (column 12) reflects the technical feasibility and the number shown provides a quantitative value reflecting readiness levels ranging from 0 to 9. Benefits that are expected for an application are indicated with an "x." In the future, it would be possible to rank or rate the magnitude of the benefits based on quantitative values such as return on investment, dollars saved, or the benefit cost ratio associated with using UAS for a given application. This kind of quantitative analysis will be more feasible in the future, as technologies mature and more information is available.

In the current prioritization, both benefits (as reflected by the Benefits Score in column 12) and INDOT interest (column 2) are assessed using a value between 0 and 9 that reflects a score or rating associated with the

TABLE 5.1
Prioritization Considerations

	1. INDOT Activities	2. INDOT Interest	Contributes to Operations: 3. Regular	Contributes to Operations: 4. Emergency	Safety: 5. Public	Safety: 6. INDOT	7. Mobility	8. Efficiency	9. Cost Savings	10. Comm., Training, & Education	11. Benefit Score	12. TRL (0 to 9)	Total Score
Bridge inspections		9	x	x	x						9	5	23
Bridge pre-inspection for safety	JTRP	9				x				x	9	7	26
Confined space inspection		3								x	3	7	13
MSE wall inspections		1	x			x					3	8	12
Aviation activities (obstruction survey)	Demo	9	x					x	x	x	3	8	21
Stockpile monitoring (salt and aggregate)	JTRP	3						x	x		3	9	15
Construction Input from E&B and Milestone and Reith Riley Contract deliverables from constructors	x	9	x					x	x	x	9	9	27
Public relations and public information		3	x	x	x		x			x	9	8	20
Traffic monitoring	Demo	1	x				x		x		3	8	12
Pavement inspections		1									1	7	9
Landslide monitoring	JTRP	3		x	x					x	3	7	13
Facility management (buildings)		3						x	x		3	8	14
Asset management (signs, culverts, etc.)		1	x					x			3	7	11
Vegetation management		1						x			1	7	9
Light pole and sign inspection		0	x					x	x		3	8	11
Incident management and documentation of scene	ISP	2								x	9	8	19
Emergency management and disaster response	x	9		x	x	x	x	x		x	9	8	26
Environmental monitoring		0									0	7	7
ADA compliance		0					x				0	7	7
Park and ride lot survey		0									0	8	8
Aerial imaging (already underway)	x	9						x		x	3	9	21
Work zone monitoring		3	x		x	x	x	x			9	8	20

Note: Topics in red had the highest scores and were prioritized for additional study in Chapter 6.

1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: GAO simplification of agency documents. | GAO-16-410G

Figure 5.1 Technical readiness level (TRL) descriptions (U.S. Government Accountability Office, 2016).

qualitative information gained from INDOT interviews and from the benefits expected (as shown in columns 3 through 11). This scoring system reflects the use of the Total Quality Management (TQM) Quality Function Deployment (QFD) method which can be used to translate qualitative judgement to a quantitative decision. QFD is a Multi-Attribute Utility Theory that has been used in the auto and aerospace industries for decades, by companies such as Ford, Boeing, and McDonnel Douglass (Vance et al., 2018).

In QFD evaluation, a composite score for each candidate project is based on scores of 0, 1, 3, or 9. A score of 0 indicates that there is no difference or preference, a score of 1 indicates a marginal or weak preference, a score of 3 indicates a measurable or medium preference, and a score of 9 indicates clear superiority or a strong preference.

The use of QFD is intended to provide a means to clearly communicate qualitative (and in some cases somewhat ambiguous) information for the purposes of discussion and transparent decision making. The information in Table 5.1 is not intended to suggest that one application is inherently preferable to another, but rather to communicate the findings of preliminary interviews, and the information available during this prioritization. Assignment of values can illuminate where differences of opinion may exist and provide an opportunity for stakeholders to share their perspectives on a variety of aspects that relate to the new technology.

The proposed framework can be used in the future as technologies mature, and the prioritization can be revised on a regular basis to identify future strategic implementation opportunities. Based on the current information, strategic implementation of UAS should be investigated in greater detail for the following applications:

- bridge inspection and pre-inspection, and bridge damage assessment,
- emergency management and disaster response, and
- construction.

These prioritized applications were presented in an interim report sent to INDOT representatives on January 28, 2019 and confirmed in a meeting on February 14, 2019. This recommendation was later validated when FHWA EDC selected the same applications in August 2019.

6. INVESTIGATION OF INDOT PRIORITY APPLICATIONS

The next three sections provide additional details regarding the deployment of drones for the prioritized applications: (1) bridge inspection and pre-inspection, (2) emergency management and disaster response, and (3) construction. These applications represent a variety of operational scenarios.

- UAS for bridge inspection safety will be used in *regular operations by DOT personnel*; this includes regularly scheduled inspections and inspections in response to bridge hits.
- UAS for emergency management and disaster response will be used in *emergency operations by DOT personnel.*
- UAS for construction will be used in *construction activities by consultants under contract to the DOT.*

These three different operational scenarios provide an opportunity to strategically implement UAS in different ways, which will support the development of organizational policy. These three prioritized applications were presented in an interim report to INDOT in January 2019 and were approved at the Study Advisory Committee (SAC) meeting on February 15, 2019. These applications were later validated when FHWA Every Day Counts selected the same three applications as priorities in August 2019.

Bridge Inspection Safety. UAS can support bridge inspection safety by providing information during pre-inspection and inspection activities, as well as information that can be used for reference after the inspection. UAS can provide information that reduces the amount of time that lanes are closed, increasing safety for the bridge inspection team as well as the traveling public. UAS can support both regular bridge inspections and bridge inspections in response to bridge hits.

Emergency Operations. UAS can support emergency management activities including emergency preparedness, emergency response, and emergency recovery. UAS provide a flexible, safe, and relatively low-cost tool to enhance investigation of the conditions during and following an emergency and provide important information to support decision making and response activities. Documentation (including video documentation) of emergency situations can be used internally to support decision making and externally, to provide public information. Data gathered via UAS provides valuable evidence that can be used when requesting federal assistance, as well as internal documentation that can be valuable when preparing for future emergencies.

Construction Activities. Many construction contractors are already using UAS for a variety of construction activities, including surveying, earthwork, stockpile measurements, site safety, and documentation of construction progress. INDOT can quickly incorporate UAS capabilities by adding the collection of UAS data to the INDOT construction contract.

Each of these applications is discussed in greater detail in the following sections.

6.1 UAS to Support Bridge Inspection Safety

As noted in the FHWA Every Day Counts for UAS, "Keeping workers out of harm's way is a major benefit of using UAS. Traditional bridge inspection requires setting up temporary work zones, detouring traffic, and using heavy equipment. UAS technology can speed data collection while reducing risk to work crews and the traveling public" (FHWA, 2019a). The use of UAS for bridge inspector safety not only provides a significant benefit by reducing potential incidents, but also provides an excellent way for transportation agencies to integrate UAS into a core activity and develop supporting protocol and policy. As UAS capabilities become familiar to bridge inspectors and other DOT personnel, team members who gain a working knowledge of UAS capabilities will be able to identify additional tasks that could leverage UAS as a tool to enhance safety and efficiency.

6.1.1 Application

INDOT can use UAS to support bridge inspection safety, and UAS can potentially increase safety for bridge inspection personnel, as well as for the motoring public.

6.1.2 Lessons Learned

UAS have successfully been used to increase safety for bridge inspection personnel and for the motoring public in a variety of ways.

- Pre-inspection activities.
  - Provide an overview of bridge condition and areas of concern.
  - Identify climb points and support safe access to bridge.
  - Identify cracks and bridge components that need extra attention.
  - Identify areas that need cleaning prior to inspection.
  - Identify nests that cannot be disturbed and other environmental considerations.
  - Identify potential wildlife hazards.
- During bridge inspection.
  - Pre-inspection UAS information reduces time required for actual inspection.
  - Reduced inspection times reduces duration of lane closures and time required for snooper (aka under bridge inspection unit or UBIU) which increases safety for motoring public and bridge inspectors.
- Post-inspection activities.
  - Images collected by UAS can be used for inspection report.
  - Data collected by UAS provides a robust record of bridge condition.
  - Video, images and data collected with UAS can be reviewed to support the bridge inspection report.
  - Historic video, images and data collected with UAS can be reviewed to assess changes in bridge condition,

which may be valuable for a regular bridge inspection and a special bridge inspection.

- Damage assessment.
  - Video and images collected by UAS may provide a unique perspective that cannot be obtained by the bridge climb team or from a bucket truck.
  - The video and images collected by UAS may support legal activities and may be useful to INDOT for litigation since it effectively documents bridge damages, such as damage due to a bridge hit.

Although there are many ways that UAS can support bridge inspection activities, it is important to note that most of the UAS data will not be a part of the official bridge inspection record.

Pre-inspection. UAS can be an excellent tool to support pre-inspection activities. The railroads have been early adopters of UAS for pre-inspection. Some rail companies have a UAS team that collects video on all railroad tracks and bridges prior to field inspection. This video is provided to the inspection team to allow a preview of the facilities that will be inspected. The preview can be used to ensure that cleaning and other required maintenance is accomplished prior to the team's field inspection and ensures the bridge inspection team can make the best use of their field time. This pre-inspection video can also be used to identify cracks or areas of concern that may need additional attention during the inspection.

Figure 6.1 shows the capability of even basic cameras, in this case a GoPro camera, which is not the best tool for this task (Dorafshan et al., 2017) since camera technologies have rapidly advanced, but does illustrate the benefits of even basic, inexpensive equipment. The use of higher resolution cameras can improve the capability to identify cracks and other defects, which may be located anywhere on the bridge. One study found that UAS had the ability to detect cracks less than a millimeter wide (Ellenberg et al., 2016). Use of a UAS for crack detection is ideal for areas over water and situations that currently require an under bridge inspection unit (UBIU, aka snooper truck) (D. Keith, personal communication, January 28, 2019). High definition cameras can be used to identify small cracks in both concrete and steel bridges, and even deformation of cables (Intel Newsroom, 2018).

Figure 6.1 Cracks in pavement recorded by UAS (Dorafshan et al., 2017).

Pre-inspection flights can also identify environmental conditions that warrant attention, such as nests that cannot be disturbed, dangerous wildlife, or other conditions that may present a hazard to the inspection team. Drones allow identification of potential hazards and conditions without the risks associated from physical contact. Drones have been used to identify vegetation characteristics (Barfuss et al., 2012), which may be helpful since vegetation may present risks (e.g., poison ivy, poison oak, and nettles). Examples of hazards that may be encountered during bridge inspection are shown in Figure 6.2.

Pre-inspection video can also be used to increase safety by identifying climb points and tie-off points, clearances and potential risks, such as sharp edges on bridge components (D. Keith, personal communication, January 28, 2019). A pre-flight of the bridge can also provide current conditions, including soil erosion near the bridge that may limit access or increase the risk of a slip or fall.

Pre-inspection drone video supports faster bridge inspections, since the team can develop an inspection plan that reflects current conditions, considering the bridge elements themselves, as well as the environmental hazards. The video also ensures that all required equipment can be identified prior to the inspection and be readily available.

Prioritizing the elements of each bridge inspection and planning inspection routes may reduce the number of times the team needs to cross roads and reduce redundancy or inspection inefficiency. Increased efficiency and safety go hand in hand since reduced inspection time in the field correlates with less lane closure time, less climbing time, and less exposure to the elements.

UAS are also able to access hard to reach places and document conditions with pictures, which can be confirmed with a follow-up hands-on inspection. The images collected by UAS relieve the inspector of having to take photos during the inspection, which reduces the need to multi-task and reduces the required inspection time. High-resolution video collected by UAS can support visual inspection requirements, but do not replace the need for hands-on inspection of fracture critical components and connections.

During Bridge Inspection. The use of a UAS for pre-inspection activities reduces the time required for the actual inspection and reduces the amount of time that equipment such as UBIU is needed. This reduces the amount of time that traffic lanes are closed and increases safety for both inspectors and the motoring public.

Since bridge inspectors have pre-viewed the bridge, they can confirm preliminary findings and then focus their field time on components that are distressed or need extra attention. UAS may also reduce the need for

(a) Confined spaces (Edwards Diving Services, n.d.)

(b) Hazardous plants (ODOT, 2014)

(c) Wildlife, including insects, reptiles, and animals (Zennie, 2014)

(d) Erosion (Swieteck, 2018)

(e) Working at height (Hot Toddy News, 2015)

(f) Traffic can cause hazards for bridge inspection team and motoring public (Oregon DOT, n.d.)

Figure 6.2 Example hazards of bridge inspection.

bridge inspection team members to cross traffic multiple times, climb under the bridge, and around the bridge. The UAS capability of flying under, over, and around bridges without hindering the flow of traffic allows inspectors to gain useful information from a safe location. The safety of the bridge inspection team is also increased if tie-off points have been pre-planned using video and images collected during the pre-inspection phase.

During bridge inspections, drones can provide real-time traffic monitoring when lane closures are required. Bridge inspectors close lanes to ensure their own safety and to inspect certain parts of the bridge (Kamga et al., 2017). These lane closures increase the risk of public safety as work zone accident rates are about 25% higher than comparable non-work zone areas (Ozturk et al., 2014).

UAS aerial views are ideal since they can capture the surrounding area (Gillins et al., 2018). UAS can be used to document traffic control (e.g., lane closure and work zone features required for bridge inspection) as well as traffic characteristics such as queue length. Although Part 107 restricts UAS from flying above people or cars, in some circumstances a drone could fly next to the road without being directly above the traffic and

TABLE 6.1
Example Hazards Associated with Bridge Inspection (Ohio DOT, 2014a; OSHA, n.d.b)

Traffic and work zone safety
Working at height
Working in isolated environments
Adverse weather
Working in the dark and poorly lit areas
Unsecured hazards in the work area
Contact with electrical lines and other utilities
Silica, nuisance, dust, dried lead or silt
Improper ladder or scaffold use
Work on, over or near water
Diving operations
Vessel operations
Power and hand tool use
Noise
Exposure to contaminated water
Confined spaces
Discovery of unknown chemicals
Vegetation: poison ivy, poison oak, thorns
Insects and animals: snakes, ticks, dogs, falcons, and raccoons

people on the road. Flight near the roadway must be conducted with caution; if the drone loses power and falls into traffic due to a gust of wind, FAA may interpret it as flight over traffic (J. Grey, personal communication, August 16, 2019).

A list of hazards associated with bridge inspection are shown in Table 6.1. Some of these will be reduced by integrating information collected by the drone. For example, if drones reduce the amount of time an inspector is working at height, and if they reduce the amount of time working in a work zone with a lane closure, overall safety will be increased.

Post inspection. Information collected by UAS provides a robust record of bridge condition, and inspectors can review all information and select the information most appropriate for inclusion in the bridge inspection report.

Historic video, images and other bridge data collected by UAS can be used to assess changes in bridge condition. Since UAS can be programmed to collect images and video when following a specific and set path, it is easy to compare data collected over time. If detailed information is needed, UAS images can be used to create accurate photogrammetric models of the bridge, which can be used to identify and document small changes in crack propagation or deflection. Photogrammetry models require high-resolution images with 60% to 80% overlap between images; standard, off the shelf software can be used to create the models. Figure 6.3 illustrates a UAS programmed flight path to create photogrammetry.

6.2 Recommended Bridges for Early UAS Deployment in Indiana

Table 6.2 shows recommended bridges that may be appropriate candidates for the introduction of UAS into bridge inspection activities. Bridges are identified

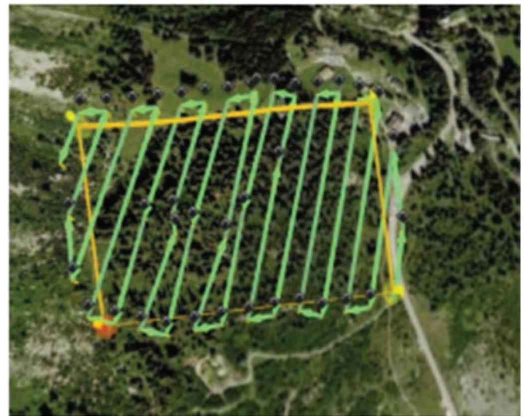


Figure 6.3 Sample UAS flight path for photogrammetry model (SPH Engineering, n.d.).

in each of the six INDOT districts. These bridges were selected because they are expected to represent a low risk environment in terms of vehicle traffic, and because they do not have airspace restrictions due to nearby airports. The bridges identified are all state assets on two lane roads with relatively low traffic volume. Low volume roads reduce potential issues related to vehicle conflicts, flying over traffic, and driver distraction due to the UAS. In the long term, UAS will provide significant benefits for large bridges that require climbing and equipment such as a UBIU. These smaller bridges, however, are ideal for the investigation of UAS for bridge inspection activities and for the refinement of supporting protocol. Other factors that should be considered include minimal surrounding obstacles such as overhead electrical wires (Brooks et al., 2014).

6.3 Special Considerations

Regulations. Bridge inspection procedures must reflect and be consistent with both FHWA requirements and regulations, as well as FAA regulations. FHWA requirements for bridge inspections reflect federal regulations initially promulgated in the Federal-Aid Highway Act of 1968. This legislation required the creation of national bridge inspection standards (NBIS), which ensures public safety through the inventory of public bridges, and the evaluation of bridge deficiencies. The NBIS requires an inspection of each bridge every two years, as well as documentation of conditions in a bridge inspection report, and maintenance of bridge inspection records. Additional special inspections may be required following a storm or if there is reason to suspect bridge damage. Inspection requirements include visual inspection, and hands-on inspection of fracture critical components and connections. Guidelines from FHWA are forthcoming (a technical memo has been drafted and is being reviewed), and it is expected that information collected by UAS cannot replace a bridge inspector's hands-on inspection. It is likely that information collected by a UAS may be used to support the visual inspection requirements. Changes to the regulatory requirements are

TABLE 6.2
Candidate Bridges for Early UAS Deployment

Parent Asset (all are state assets)	Asset Name	NBI 002: District	NBI 003: County Code	NBI 006: Feature Intersected	NBI 007: Facility Carried by Structure	NBI 008: Structure Number	NBI 009: Location	NBI 029: Average Daily Traffic (ADT)
Crawfordsville	041-23-03932 B	1	23	EAST FORK COAL CREEK	US 41	15190	00.52 S US 136	2,109
Crawfordsville	041-23-03885 A	1	23	COAL CREEK	US 41	15280	02.52 S SR 55	3,529
Crawfordsville	041-23-06535	1	23	WABASH RIVER	US 41	15320	00.57 N SR 28	9,400
Fort Wayne	001-17-06097	2	17	SOL SHANK DITCH	SR 1	490	00.10 S SR 8	717
Fort Wayne	001-17-06868 A	2	17	METCALF DITCH	SR 1	500	02.41 N SR 8	3,210
Fort Wayne	001-17-06879 A	2	17	BIG RUN	SR 1	510	00.51 N US 6	1,553
Greenfield	003-70-06632	3	70	LITTLE FLATROCK RIVER	SR 3	830	01.46 S SR 244	4,898
Greenfield	003-70-01483 B	3	70	LITTLE BLUE RIVER	SR 3	850	04.81 S US 40	4,798
La Porte	049-37-03702 B	4	37	WOLF CREEK	SR 49	17920	01.56 S SR 10	2,607
La Porte	049-37-01938 C	4	37	KANKAKEE RIVER	SR 49	17940	04.59 S SR 8	5,140
Seymour	135-88-07865	5	88	BEAR CREEK	SR 135	26390	04.18 N US 150	2,239
Seymour	135-88-03939 A	5	88	MUSCATATUCK RIVER	SR 135	26450	03.76 S SR 235	2,120
Vincennes	065-26-00313	6	26	BLACK RIVER	SR 65	23210	02.09 S SR 168	1,662
Vincennes	065-26-03901 B	6	26	PATOKA RIVER	SR 65	23250	02.88 N SR 64	1,890

not likely in the short term but would affect the future utilization of UAS for bridge inspection. Similarly, while it may be useful to collect data with UAS, it would not be appropriate to include all the UAS data collected in the bridge inspection report, due to the requirements related to the maintenance of bridge inspection report information. The bridge file refers to all documents necessary to provide a comprehensive history of each bridge asset. Currently, INDOT utilizes the Bridge Inspection Application System (BIAS), and the Electronic Records Management System (ERMS) to maintain bridge records. The vast amount of data that can be quickly collected by UAS would result in significant data, significant storage expense, and would likely cause challenges in maintaining the data and ensuring timely access to needed information.

FAA regulations under Part 107 were previously discussed; these regulations currently include limits on flight over moving vehicles and beyond visual line of sight (VLOS). Both of these regulations have been waived under some conditions. The FAA provided a waiver for operation of a drone with the ParaZero SafeAir parachute system for flight over people and beyond visual line of sight. In this case, the parachute was part of the risk mitigation strategy. There may be other risk mitigation strategies to support drone flight over traffic and beyond VLOS (McNabb, 2019). In one mission flown under the waiver, the drones supported real-time data for public safety and traffic management (McNabb, 2019).

Rapidly Advancing Technologies. Bridge inspection safety can be significantly enhanced by the use of a camera mounted on a UAV. UAS can also be used in conjunction with advanced technologies and processing software. UAS data can be used to support sophisticated GIS models of the bridge, which allow data to be stored by location and correlation with the specific bridge component. This allows measurement and tracking of cracks and other visual characteristics and allows geo-tagging of more advanced data on bridge elements, such as thickness of components, and thermal images of the bridge deck to assess delamination; thermal images are provided by an infrared camera mounted on a UAV.

There are many potential uses for thermal imaging and other advanced sensor technologies, ranging from identifying delamination on the bridge deck (Wells & Lovelace, 2018) to detailed 3D models. The infrared images can show a variety of details (MnDOT, 2017). The infrared or thermal camera on the UAS can be useful for detecting concrete delamination on the bridge deck. MDOT used thermal imaging to identify areas of delamination and later verified it with hammer testing (Brooks et al., 2014). One study in Canada found thermal imaging results were comparable to hammer sound tests (Omar & Nehdi, 2017). Another study, searching for ways to detect water in historic masonry bridges, found that infrared thermography could be used for nondestructive methods of testing, even noting that vegetation and angles of the stones could be detected (Lagüela et al., 2012). As shown in Figure 6.4, thermal imaging can be used to support identification of pavement distress, as illustrated by these images taken from a NCDOT study (Zajkowksi et al., 2016).

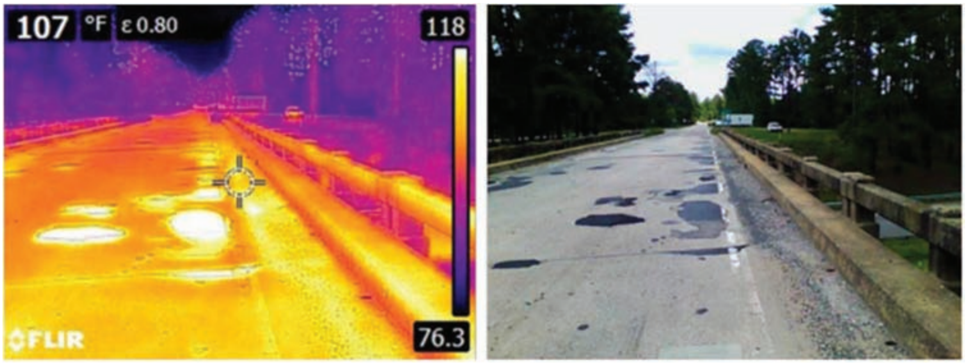


Figure 6.4 Thermal imaging of bridge deck (Zajkowski et al., 2016).

Thermal imaging can identify delamination on bridge decks before it is visible and may increase safety since it can be done quicker than traditional methods, such as chaining.

There are many other sensors and technologies that are being developed that can be used with a UAV to support bridge inspections. In addition to infrared, other non-destructive testing (NDT) technologies, such as ground penetrating radar, LiDAR, electrical resistivity, and ultrasonic pulse velocity can be used to detect delamination, cracking and other distresses (Fahim, 2018; FLIR, 2016). These technologies can be mounted on UAV, mounted on a vehicle, handheld or stationary unit, however, mounting the sensors on a UAV may allow access to bridge areas that are hard to reach, and facilitate the use of standard software to process and record data in a structured format that incorporates GIS reference points. Many of these technologies allow bridge inspectors to identify deterioration earlier, before damage is visible. Traditional and newer sensors are shown in Figure 6.5.

Ground penetrating radar is used to assess the corrosion of metal reinforcing in concrete bridges. Ground penetrating radar may be mounted on vehicles or manual units, and recently the military has mounted units on drones (Miller, 2019).

LiDAR has been used to map bridges and other infrastructure and is one of the technologies investigated for bridge inspections by a number of agencies, including integration with UAS by MnDOT and Michigan Technological University. As these technologies advance, their use with UAS may further enhance safety by reducing the amount of field time required to conduct condition assessment, which reduces exposure to hazards for both the bridge inspection team and the motoring public.

Data collected by UAS can be used to make 3D models. 3D models can be used to represent current conditions, as well as show defects, erosion, and scour data. MDOT has used optical imagery to create a 3D model of the bridge deck, which combined with software was able to identify spalling on the bridge deck (Brooks et al., 2014). 3D models can also be used to plan out the inspection of the bridge. The 3D model can be easily shared between engineers, inspectors, and other stakeholders. Another 3D application is the use of a digital terrain model or digital elevation model, which allows a digital tour of the surrounding area for people unable to attend inspection sites. Digital terrain models can be constructed using small LiDAR sensors attached to a UAV (Gillins et al., 2018). 3D mapping of a bridge may include the bridge and erosion data for the earth around the bridge; this 3D map may be developed with detailed images, infrared images, and 3D software modeling capabilities. Data taken over a number of years, combined with the GPS capabilities and the appropriate software, may be used to show how the area changes over time, also known as geo locating. Figure 6.6 shows a 3D model created from UAS data (Irizarry & Johnson, 2019).

Public Information. The bridge inspection time and reduced need for snooper trucks reduces lane closure time and saves taxpayer money (Intel Newsroom, 2018). Faster inspections reduce the impact on the traveling public. However, drones may cause a distraction for drivers as long as they are a novelty. Some DOTs post signs where drones are being used in an effort to reduce driver distraction, although it has also been suggested that the warning signs could cause increased distraction since they may cause drivers to look for the drones. TxDOT posts a surveying ahead sign followed by a drone inspection sign (TxDOT, 2017). Figure 6.7 shows an example of a warning sign that can be used.

Video collected by drones has also been used to provide public information, and to support public awareness campaigns. For example, WSDOT has used UAS videos on its twitter feed to share information about maintenance progress on bridges, as well as lane closures and closures due to snow (WSDOT Traffic [@wsdot_traffic], 2018). Sharing video collected by UAS that increases public knowledge, e.g., explains why a bridge or lane closure is necessary, may improve public safety and support public relations.

UAS Teamwork and Equipment. Florida Tech worked with FDOT to inspect five bridges and found that successful UAS deployment leveraged the expertise of

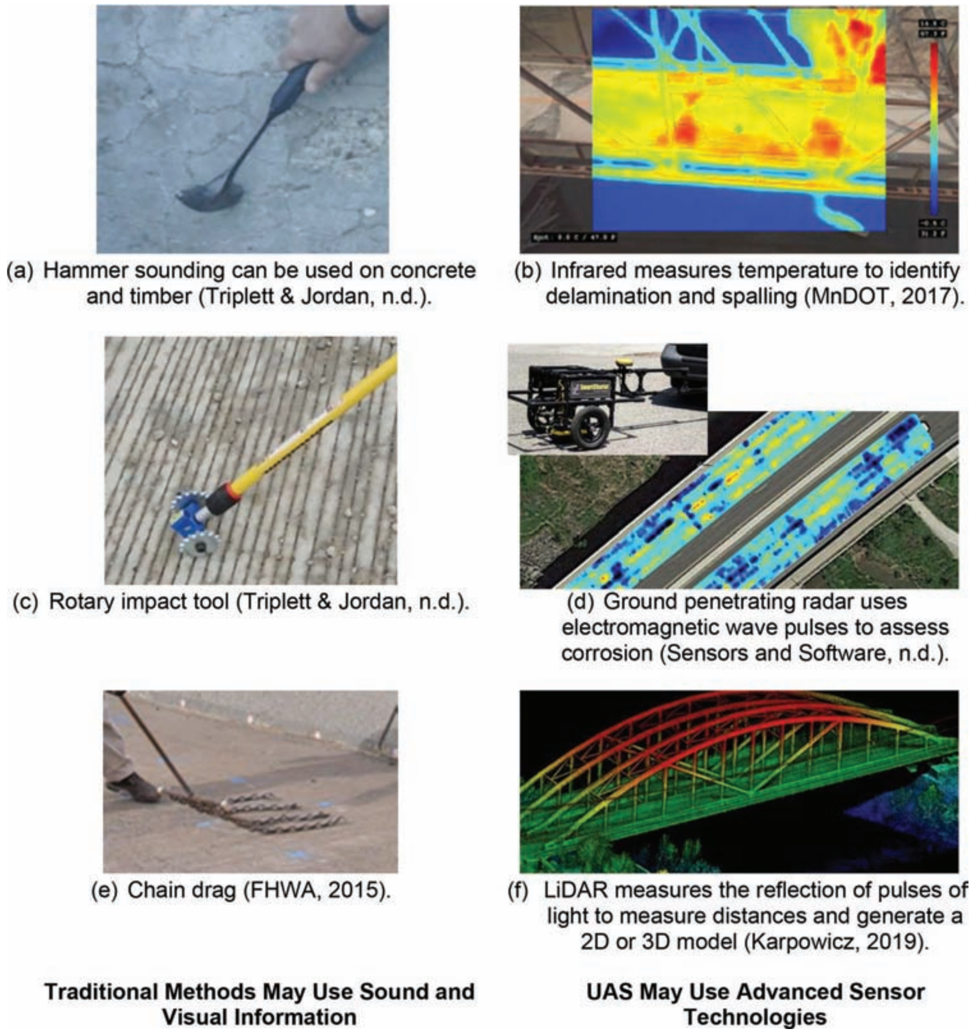


Figure 6.5 Example tools for bridge inspection.

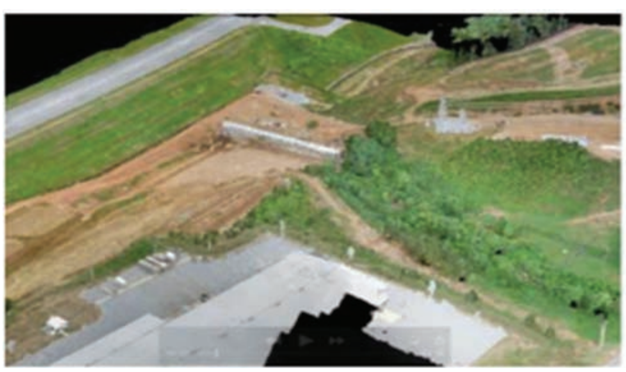


Figure 6.6 3D model created from UAS data (Irizarry & Johnson, 2019).

Figure 6.7 Drone inspection warning sign for motorists (Zink, 2015).

bridge inspectors. UAS pilots worked closely with FDOT inspectors, who provided guidance during the flights (Otero et al., 2015). During a flight of the Concrete Girder Highway Bridge, an FDOT inspector watched streaming real-time video data from the flight and provided feedback regarding the usability of the video images for inspection documentation, and guidance that allowed the pilot to focus on the bridge areas of greatest interest (Otero et al., 2015). Overall, the inspectors were impressed with the quality of images.

Many of the field tests demonstrated how an UAS could be used to inspect bridge components that could typically only be reached by a bucket truck (Otero et al., 2015).

The team produced high quality video and photography collected during the flights. The imagery showed hard to reach places on the bridges and allowed identification of areas with significant rust, stress cracks and longitudinal cracking (Otero et al., 2015). On the steel railway drawbridge, the team was even able to identify that the bolts appeared to be in critical condition (Otero et al., 2015), as shown in Figure 6.8. UAS images can be used to identify rust on bolts, rails and gusset plates (D. Keith, personal communications, January 28, 2019). For the study in Florida, images used were corrected for distortion (i.e., fish-eye) before they were analyzed (Otero et al., 2015).

The team used a quadcopter and a hexacopter. One experiment was conducted with gusts of wind up to 18 mph. The pilot was able to keep the quadcopter stable in the confined space. However, the hexacopter had problems remaining stable in a confined space for a prolonged period of time due to the "turbulence effect" (Otero et al., 2015).

Although no longer available, MnDOT used the senseFly Albris for a number of reasons. The camera on the senseFly can be rotated upward to easily capture images of the underside of the bridge deck (Wells & Lovelace, 2018). The senseFly Albris can fly without a GPS signal, which is useful under bridges where the signal is blocked, as well as in remote locations (Wells & Lovelace, 2018). The senseFly Albris is also rugged, which allows the UAS to be flown close to the bridge with less worry of potential damage to the drone.

6.4 Results of Survey of Bridge Inspectors

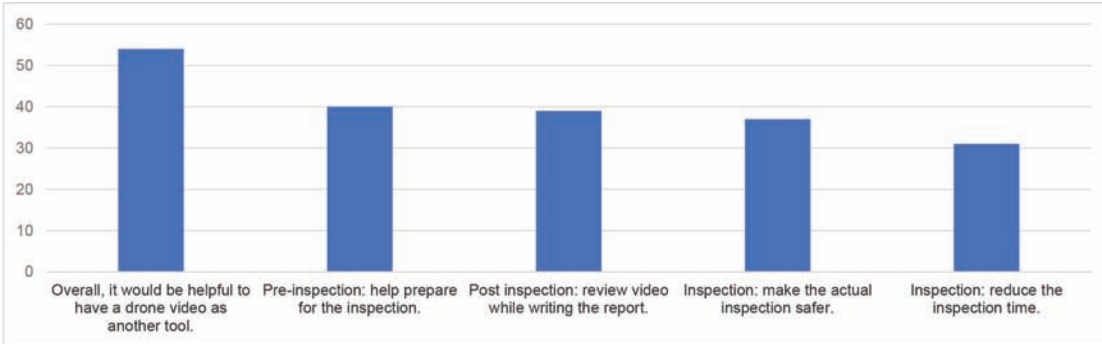
An online survey of bridge inspectors was conducted to learn more about their perspective. All responses were anonymous. The survey was distributed using the INDOT bridge inspection listserv, which includes bridge inspectors who work for INDOT, as well as consultants who do bridge inspections under contract with INDOT and Indiana counties. Bridge inspections for all bridges on the Indiana state highway system are managed by INDOT, and all local bridges serving county, city, and towns roads are managed by the county, and are typically contracted to private consulting agencies that conduct the inspections.

Additional results from the survey are shown in Figure 6.9. Responses indicate the 83% of those surveyed (54 of 65 responses) believe overall it would be helpful to have drone video as another tool. The majority indicate drone video would be useful for pre-inspection (most often cited answer with 62%), post-inspection (60%), and during the actual inspection (57%).

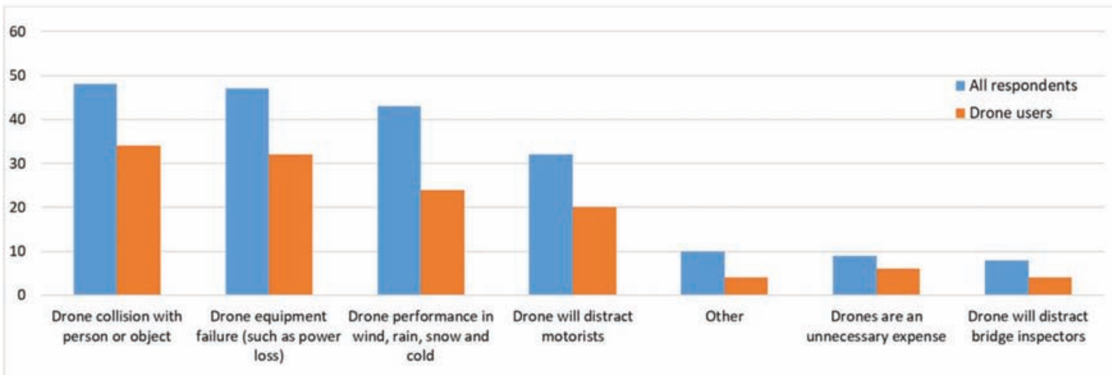
The greatest concerns for bridge inspectors are working near moving traffic and distracted drivers. When working with a snooper truck, the third cited concern was falls from height. When not using a snooper truck the third cited concern was slips, trips, and falls. All of these concerns are validated by national statistics regarding worker injuries and accidents in a highway work zone.

Top concerns regarding drone use for bridge inspection include a collision with a person or object, a drone equipment failure, or the capability of the drone to perform in harsh conditions, such as wind, rain and cold (Figure 6.9b). Drone battery life is compromised by cold, and there are limits regarding the capability to

Figure 6.8 Rusted bolts on steel bridge detected by UAS (Otero et al., 2015).



(a) Responses to question "What would drone video be useful for?"



(b) Responses to question "Top three concerns regarding drone use."

Figure 6.9 Results of survey of bridge inspectors.

safely navigate drones in windy conditions. It is notable that the concerns regarding drone use are significantly lower for respondents who have experience using drones, than for all respondents. Respondents with drone experience provided the following comments regarding concerns with drone use:

- No concerns. Totally worth it.
- Useful for general inspection only, have strong reservations regarding fracture critical inspections/complex inspections.
- Not being able to adequately see and feel the area being inspected. In person is always better than a photograph.
- They should be used for safety and cost savings.

The concerns center less on the risks associated with drone use, and more on concerns that drones would replace hands on inspection. The proposed use of drones would not replace hands on inspection but would enable the use of drones as another tool in the inspector toolbox. Additional information about the findings from the survey of bridge inspectors is provided in Appendix F.

6.5 Case Study: INDOT Uses UAS for Bridge Damage Assessment

On January 23, 2020, a vehicle hit and damaged the bridge on US 41 southbound at the Little Pigeon River, north of Evansville. INDOT deployed a team to conduct damage assessment on January 28, 2020; the team included the bridge climb team, inspectors using a bucket truck, and a remote pilot and UAS.

The UAS was operated in coordination with aeronautical activity at the Evansville Regional Airport (EVV), a non-hub primary service airport that provides scheduled commercial service with United, Delta, American, and Allegiant Airlines. Due to the close proximity of the airport, the drone was limited to altitudes of 100 ft or less. The video provided by the drone at this altitude was adequate for the needs of the damage assessment. Overall, the UAS team was able to work within the constraints of air space restrictions and able to collect valuable video.

The weather was near freezing, which required the team to use four batteries since battery life was reduced due to the cold weather. The UAS provided valuable video and images, with a unique perspective that could not be obtained by either the climb team or personnel in the bucket truck.

In terms of documentation for the future, the UAS video was uploaded to INDOT's BIAS system, the system that maintains records INDOT bridge assets, and will be useful for any future legal issues related to the bridge hit. Photos for the case study are shown in Figure 6.10.

(a) UAS provides excellent vantage point to document bridge damage after bridge hit (Fitzgerald, 2020).

(b) UAS can document areas of bridge that are difficult to access (Fitzgerald, 2020).

Figure 6.10 INDOT case study: UAS supports bridge damage assessment.

6.6 UAS for Emergency Response

UAS can be used to support emergency management activities, including emergency preparedness, emergency response, and emergency recovery. UAS provide a flexible, safe, and relatively low cost tool to enhance emergency response and support investigation of the conditions during and following an emergency. UAS provide important information to support decision making and response activities.

6.6.1 Application

INDOT can use UAS to support emergency management for local or regional emergencies, such as roadway and bridge closures due to tornado, flood, landslide, bridge failure or hazardous spill, and for statewide emergencies, such as an earthquake.

6.6.2 Lessons Learned

UAS have successfully been used for disaster response for more than a decade and provide a low-cost means for imagery and other data. UAS were utilized before Part 107, and have provided value for a variety of natural disasters, including:

- U.S Hurricanes Katrina and Wilma in 2005 (Murphy, 2014),
- Typhoon Morakot in Taiwan in 2009 (Adams & Friedland, 2011),
- Earthquakes in L'Aquila, Italy in 2009, Haiti in 2010, and Japan in 2011 (Adams & Friedland, 2011),
- Thailand floods in 2011 (Srivaree-Ratana, 2012),
- Typhoon Haiyan in 2013 (Alschner, 2016),
- Flooding in Boulder, Colorado, in 2013 (Cervone et al., 2016),
- Mudslides in Oso in 2014 (Murphy et al., 2016b),
- Balkans flooding in 2014 (De Cubber et al., 2013), and
- Forest fires in California in 2018 (Cosgrove, 2018; Hidahl, 2018).

FAA reports that UAS is increasingly being leveraged as a valuable tool in emergencies, with more than 600 emergency COAs (aka Special Government Interest (SGI) airspace authorizations) were issued in the first six months of 2019, compared to 708 in all of 2018

(Speed, 2019). In many cases, UAS are used to collect photos and video for real-time decision-making, and to support internal and external communication, as well as to create photogrammetry maps that can be used for measurements. The small size of UAS, their low cost and their ability to access areas inaccessible by roads make them very valuable during an emergency. Their capability to carry a variety of sensors make them very flexible and may allow them to access areas before humans can, for example, in the event of a hazardous spill.

Information collected by drone can be very valuable for decision making, so it is important to document the information used when decisions are made. *The timeline of the data-to-decision process may be very valuable after the fact to justify decisions* (Murphy et al., 2016b) and to identify how drones may be used in future emergencies to ensure the right information is available when needed.

As early as 2005, UAS were used to conduct inspections of commercial buildings damaged by Hurricane Katrina (Pratt et al., 2006). The resulting photos and video imagery illustrated the potential for data collection and assessment after a disaster, and identified *potential issues such as site access, sensor coverage, weather conditions and obstacle avoidance* (Pratt et al., 2006).

The data collected via UAS can be used to create real-time hazard maps (Suzuki et al., 2008), which can be used for both emergency responders and to communicate with the public. Imagery may provide a more compelling case for evacuation, and once evacuated, may provide information to the public regarding the condition of their neighborhood. A real-time hazard map is shown in Figure 6.11.

Although UAS can be used to assist with search and rescue operations in the recovery phase, many agencies do not perform this function, seeing as it is considered outside the scope of INDOT's responsibilities. It will not be addressed in this document. Moreover, UAS are typically not used to identify people in distress or provide search and rescue missions since cellphones are generally resilient to floods and provide a better mechanism for these missions (Murphy et al., 2016a).

UAS were used to support disaster recovery in Taiwan after Typhoon Morakot, seeing as the resulting landslides, floods, and infrastructure damage limited travel (Chou et al., 2010). The importance of UAS for assessment following this disaster emphasized the importance and value of the data collection protocol. UAS were used in conjunction with unmanned water vehicles to support disaster recovery after Hurricane Ike (Murphy et al., 2009).

UAS may also be used to support activities before the emergency. Data collected before the disaster may be important to document changing conditions (e.g., compare deflection in bridges, crack propagation, or other infrastructure changes). In some cases, such as earthquakes, it may be difficult to correlate post-event conditions with pre-event data (Rathinam et al., 2008). When significant damage causes dramatic changes in topography that make image location reconstructed through ground control points (GCPs) with known locations in a reference system infeasible, it may be possible to use images from flight combined with computations based on the UAS exterior orientation position (x, y, and z) and rotation data (yaw, pitch, and roll).

While the orientation position and rotation data are not accurate enough for direct georeferencing, the data can be used to provide approximate orientation (Peng et al., 2018).

The potential benefits of UAS are significant throughout an emergency, and UAS can support activities in each of the four phases of emergency management, as shown in Table 6.3.

Floods are the most common natural disaster in the world (Red Cross, 2005) and in the U.S, they cause the greatest property damage and loss of life (Kousky & Michel-Kerjan, 2017). UAS are used before, during and after floods for a number of tasks including the following (Murphy et al., 2016a):

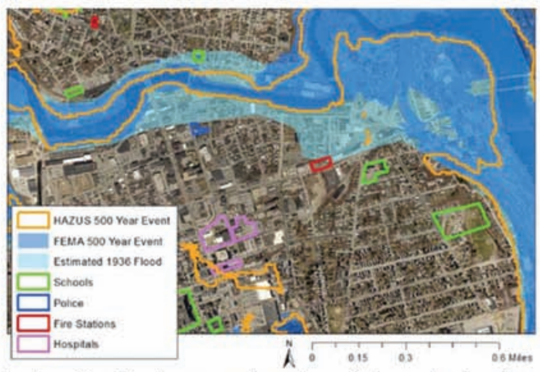
- document existing conditions before the disaster,
- predict the impact of the disaster,
- monitor the impact of the disaster,
- provide visuals to communicate with public regarding the need for evacuation, and
- document damage to request federal assistance, and for future use including public education, training, and future mitigation activities.

FHWA (Murphy, 2019) identifies seven missions for UAS during emergency management, as shown in Table 6.4. Four of these mission activities relate closely to INDOT responsibilities, including situational awareness, survey, and reconnaissance; structural inspection; damage assessment and flood estimation; and tactical situational awareness. These activities generally support the response and recovery phases of emergency management, as presented in Table 6.3.

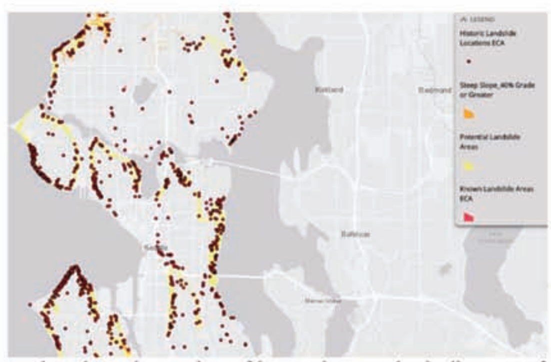
The INDOT responsibilities identified in Table 6.4 are generally consistent with the mission objectives reported by Murphy et al. (2016b) in response to a mudslide, two of which required advanced data processing and visualization. The first objective was to provide comprehensive imagery, which would be used to anticipate and mitigate flooding. The second objective was to provide a rapid 3D map and 3D site reconstruction. The third objective was to collect imagery over several days to ensure the safety of responders with respect to the possibility of slide movement. Also consistent with expected INDOT responsibilities, there was no mission to search for survivors or for victim recovery.

While UAS may be very useful in an emergency, there may be associated challenges including hazardous environmental conditions, such as wind, downed power lines, and compromised GPS signals. These conditions may make operation of UAV more difficult (e.g., obstacle avoidance may be unreliable due to wind shear).

(a) Real-time map reflects status of fire over three-day period in Spain (San Juan et al., 2018).



(b) Base maps can include critical features such as hospitals and schools as well as roadways and bridges (NESEC, n.d.).



(c) Seattle has developed a series of hazard maps including one for landslides (Seattle Hazard Explorer, 2015).

Figure 6.11 UAS data support real-time hazard maps.

Once the emergency occurs, UAS can collect information to support agency decision-making, including an assessment of current conditions, and the development of a plan for recovery. The text below illustrates emergency management considerations using a case study of two floods in Texas, described in detail by Murphy et al. (2016a). Much of the framework described would be equally applicable to other kinds of emergency response activities.

For emergency response for two floods in Texas, twenty-one flights were conducted over four days (Murphy et al., 2016a). All flights were in manual mode with an average flight time of 10 minutes, and a maximum flight time of 20 minutes (Murphy et al., 2016a). Missions after the first flood (April) focused on flood mapping and projection of impact due to the rising flood. A month later, missions after the second flood focused on verification of flood models, flood monitoring, public information, and justification for publicly accountable decisions. All missions were conducted prior to Part 107 under a Section 333 exemption (April missions) and under a Lone Star FAA UAS Center Blanket COA (May missions) (Murphy et al., 2016a). This illustrates the value of mutual aid agreements and collaborative partnerships. It may be useful to identify potential mutual aid partner agencies that have a COA or FAA approved waiver as part of emergency preparedness.

TABLE 6.3
Potential UAS Applications for Four Phases of Emergency Management (FAA, 2010; FEMA, 2006; Ramsey, 2019).

Phase	Examples	UAS Applications
Mitigation		
Take actions to prevent future emergencies or minimize effects of an event when it occurs.	Budgets that allocate resources for emergency response equipment and planning is mitigation. Constructing infrastructure with resilient design is mitigation. Public education to minimize the effects of an event is mitigation. Hazard mitigation reduces the impact of emergencies and includes any activities that prevent an emergency, reduce the likelihood an emergency, or reduce the damaging effects of an emergency.	Monitor development in flood hazard areas. Map and document pre-disaster conditions. Monitor hillsides subject to landslides. Monitor fuel loads in forests and natural areas. Monitor dams, bridges and other infrastructure to identify vulnerabilities.
Preparedness		
Take actions to enhance response capabilities and preparation to handle an emergency (preparedness activities occur *before* an emergency).	Emergency plans, evacuation plans, training, drills and exercises are preparedness as are any other plans or preparations made to save lives, increase readiness and the ability to help response and rescue operations. Stocking food and water is an example of preparedness, as is public information that tells people how to prepare and respond if an emergency occurs.	Support training and exercise activities. Preplanning and familiarization for tactical responses. Provide high resolution aerial photos of hazard areas, evacuation routes, and safe zones. Provide video to support public information activities.
Response		
Time-sensitive actions taken when an emergency occurs (response activities occur *during* an emergency).	Mobilizing emergency response personnel and equipment, evacuation, and alerting the public are all response, as are all actions during the emergency to save lives, protect property and the environment. Response is putting your preparedness plans into action. Seeking shelter from a tornado, turning off gas valves in an earthquake, and deploying emergency equipment are all response activities. Provide timely and accurate information to the public.	Provide real-time situational awareness of threats and hazards (to support public information and responder safety and decision making). Assess conditions of inaccessible, hazardous, and/or contaminated areas (images and sensors). Determine status of roads and critical infrastructure. Provide geospatial references and navigation. Monitor response operations and effectiveness. Monitor the movement of persons, vehicles, resources, and provide security.
Recovery		
Actions taken after an emergency to restore community to pre-emergency conditions.	Reconstruction, rehabilitation, public information and hazard-reduction programs are recovery, as are all actions taken to return to a normal or an even safer situation following an emergency. Recovery includes getting financial assistance to help pay for the repairs.	Survey, support and restore infrastructure, communications and utilities. Assist search and rescue operations. Video documentation may be used to support requests for federal disaster funds.

TABLE 6.4
FHWA Seven Missions for UAS During Emergency Response (Murphy, 2019)

FHWA Mission Activities	Expected Relevance for INDOT
Situational awareness, survey and reconnaissance	Real-time video and imagery for situational awareness. Photogrammetry maps for surveying and reconnaissance. Identify flooding locations, state of roads and bridges, public information, support evacuation orders and identify hazards.
Structural inspection	Examine bridges and other built structures.
Ground search and rescue	No direct INDOT responsibility for search and rescue.
Water search and rescue	No direct INDOT responsibility for search and rescue.
Damage assessment, flood estimation	More detailed than general reconnaissance, with focus on boundaries of flood, and quantifying extent of damage. Includes documentation of drainage issues to be fixed in the future.
Tactical situational awareness to support rescue teams	Traffic monitoring and detour routing, transportation planning.
Delivery	No direct INDOT relevance since UAS payloads are very small and INDOT material requirements are generally large.

Typical flight crew roles for emergency management are described in Table 6.5. The size of the flight crew varies. In some cases, one person may fulfill multiple roles. For example, the visual observer may also manage the data, and the licensed remote pilot may be the operator. In other cases, more than one person may be required for each role. One consultant reported using up to four visual observers for a single flight. Emergency

TABLE 6.5
Tasks Required for UAS (one person may fulfill multiple roles in some cases)

Crew		Responsibility	FAA Certification
FAA licensed part 107 remote pilot	 (Photo of remote pilot provided by Zach Miller. Photo of Part 107 license from (Drone Mastery, 2018).	Compliance with FAA rules and oversight of all aspects of flight and mission, including compliance and safety.	Current Remote Pilot Certificate issued by FAA under Part 107.
Visual observer (may need more than one)	 (French, 2017)	Keep UAV in visual line of sight (without the aid of binoculars) and ensure safe operation. Maintain communication with remote pilot and operator.	None
Operator	 (UAV Cinema, n.d.)	Manipulate controls for drone and avoid manned aircraft. May observe drone operation through first person view.	None
Data management (may occur as data is collected or after all flights are completed)	 (Kesteloo, 2018)	Ensure field data is transferred, processed and saved in usable format for future use.	None
Local expert (in the field with team)	 (DJI, 2015)	Provides local knowledge, makes decisions in the field, supports communication (e.g., with emergency management personnel, property owners, and curious people nearby).	None

response following a flood required up to five visual observers, taking turns (Murphy et al., 2016a). Multiple local or agency experts may be needed to help manage citizen inquiries, provide information about local conditions, and help identify ways to access areas constrained by the disaster (Murphy et al., 2016a).

A traditional rule for crew size reflects a human to robot ratio of three people for one UAV with camera (Murphy et al., 2016b):

$$\text{Nhumans} = \text{Nvehicles} + \text{Npayloads} + 1.$$

This ratio may vary substantially depending on a variety of factors, including the environment, hazards, and whether using manual mode or programmed flight.

Clearly defining protocol, responsibilities, and roles for each crew member is key to successful outcomes. Rhode (2018) suggests that key skills include: prioritizing activities to amidst distractions, working together effectively, shared understanding and a common strategy, coordination with other responders, and decision making. It is also important to make sure that there is a protocol to share information with teams on the ground, and incident mapmakers in a timely manner; in some emergencies the timeline may be a short as 15 minutes (Cosgrove, 2018).

6.6.3 Special Considerations

Data Management. Data management is an important activity, and it's required to ensure that the data collected can be leveraged for the most benefit. Data management activities may take place in the field or at the Emergency Operations Center (EOC), where there may be a dedicated data manager. Data management includes the following activities (Murphy et al., 2016a):

- backing up the raw data,
- organizing the recorded data and field data into folders using naming techniques to describe the date and location,
- editing high value data so it is easily available,
- producing flight summaries (describe the coverage and findings of each mission),
- physically transporting the data to the appropriate representatives, and
- applying post-processing software.

Development of a data management policy, assignment of a data manager, and allocation of adequate resources (personnel, hardware, and data storage) is key. The importance of a strong protocol for data management helps ensure that all data is fully leveraged and available when it is needed. The data management policy must also address data ownership, and rules regarding agency permission to release video, for both agency personnel, contractors, and volunteers (Murphy, 2019). The data management policy should address personal social media accounts, as well as official releases and publication.

The value of data depends on its availability to support decision makers; for this reason, documenting when data is available in the context of event chronology and decisions is important (Murphy et al., 2016a). Data products may include low-resolution video, high-resolution video, high-resolution images, visualization of UAV flight paths and image coverage, interactive measurement tools, and photogrammetry (Murphy et al., 2016a). Ideally, low-resolution video would be continuously available to the field team and would stream in real-time to the EOC.

In the Texas flood case study described by Murphy et al. (2016a), high-resolution video and imagery from the onboard SD card were available to the field team upon landing (12 to 20 minutes after the flight), and to the EOC and the Office of Emergency Management (OEM) when the field team returned to the EOC. The upload times varied, typically from 2 to 6 hours after the flight. In some cases, county experts with the field team were able to make decisions or provide the relevant information via phone to the EOC (Murphy et al., 2016a).

According to FHWA, a single 20-minute flight can result in 2 gigabytes (GB) of data, so it is important to ensure adequate storage and data processing capacity is available (Murphy, 2019). Case studies suggest data requirements may be even higher. For response to the Texas floods described by Murphy et al. (2016a), 63 min of video collected in one day resulted in 27 GB of raw data that produced 40 GB of raw data and data products.

UAS data include raw data, which are available without additional processing, and derived data products, which may be too expensive, too procedurally complex or time consuming to use in an emergency (Murphy et al., 2016a). Raw data products include low-resolution images and high-resolution video and images. Raw data may be recorded or not recorded (aka ephemeral). Real-time, low-resolution video is often not recorded. Depending on the equipment and software used, the UAS may record high-resolution video and geotag the images with the data saved to an SD card. Ephemeral live feed data may be adequate for an expert in the field or at the EOC to make decisions regarding resource allocations and whether the impacts are consistent with predictions. Derived data products are produced by post-processing the raw data. They often use software that was purchased with the UAS or from a third party, and include visualization of the UAS flights, interactive measurement tools, and photogrammetry (Murphy et al., 2016a). There are significant challenges due to the volume of data, and it is not unusual for data collection efforts to be duplicated; similarly, data that may be useful to multiple agencies, or even different divisions within a large agency, may not be accessed and leveraged for full benefit.

Site Selection. Travel to sites of interest during or after an emergency may require significant time, and travel time will be increased due to closed roads and hazardous conditions. The type of drone and payload used will affect the travel time. Drone flights covering larger areas will require longer travel times to the next target area. Murphy et al. (2016a) reported team drive times ranged from 10 to 45 minutes between sites. Although the set up time may be modest (e.g., less than 15 minutes), it may be necessary to visit several sites before finding an appropriate location for UAS launch and landing near the targeted area. FHWA (Murphy, 2019) notes that boats may be the fastest way to travel during a flood, and UAS may be deployed from boats with care, as shown in Figure 6.12.

During the Texas floods, one site with sufficient space and distance from power lines was rejected due to massive insect and reptile swarms fleeing the rising water (Murphy et al., 2016a), which illustrates the range of hazards that may exist in an emergency. Public safety UAS expert Steve Rhode notes that for an emergency related to an accident or incident, the least safe landing site for the UAS is at the incident scene due to congestion and distraction (Rhode, 2017). Although being at the scene has the advantage of being collocated with the incident commander, it poses a greater risk to safe operation, a greater risk to other members of the response team, and a greater risk to the public (Rhode, 2017). It is preferable to find a landing site away from the incident scene, and exchange information via a radio and/or streaming video, which can be accomplished via a private live stream video channel on YouTube or an advanced UAS incident software (Rhode, 2017). Other challenges with respect to site selection include that access points such as raised roads or levees, which are desirable in a flood. Murphy reported that one flight had an uncontrolled flyaway during takeoff (Murphy et al., 2016a).

In some cases, challenges related to launch and landing sites, or a large area of interest, may make it more practical to utilize conventional manned aircraft (such as Civil Airport Patrol) rather than UAS. Similarly, use of a larger UAS or UAS operation beyond visual line of sight (i.e., not under Part 107) may be appropriate. In some cases, drones can be effectively used in conjunction with manned aircraft during an emergency. During fires, drones with infrared capabilities provide information about the fire while keeping firefighters and emergency responders safe; drones may allow sighting of multiple fires in excellent detail and allow the provision of near real-time information to fire fighters fighting the blaze (Cosgrove, 2018). With trained pilots, unmanned drones can operate
in high temperatures, fly at night, in heavy smoke, and get to the scene quicker than a fire engine (Hidahl, 2018).

Equipment Selection. There are a variety of considerations when selecting the most appropriate sUAS, as the COPIED heuristic (Murphy, 2019):

- **C**onstraints,
- **O**perator factors,
- **P**enetration or distance,
- **I**nformation the sUAS provides to whom and when,
- work **E**nvelope for the sUAS (including altitude, weather, range and presence of manned aircraft), and
- **D**uration of flight.

The constraints, work envelope and duration of flight may be the primary factors in the selection of a platform. Typical flight durations may be 8–12 minutes, or up to 30 minutes for mapping missions (Murphy, 2019). Murphy et al. (2016a) reported four to five flights (with as many as eight flights) conducted over four days in response to two floods. These flights were about 10 minutes on average, with the longest flight 20 minutes, and used standard, off-the-shelf quadcopters. Quadcopters provide advantages such as vertical takeoff, and the capability to support high-resolution cameras to capture video and images. Operating within the constraints of Part 107 is adequate in many cases. The flights described by Murphy et al. (2016a) were 390′–395′ above ground level (AGL), within 0.5 miles in order to stay within visual line of sight, and below 400′ AGL.

The visualization tools provided by the UAS support planning, management, and a visual damage assessment and in some cases the capability to measure the impact (e.g., amount of flood water at locations of interest). In many emergency management missions the main objective is video and images. Rapid data acquisition with low-resolution video is often available during the flight, and ideally can be streamed in real-time to the EOC. The provision of a real-time display to allow experts to view the output and provide directions is consistent with studies of hazardous materials experts and sUAS (Peschel & Murphy, 2013). High-resolution data is usually available upon landing; this framework can provide data for immediate or near-term decision-making, and is different than an informatics model of flying, that utilizes processing in the cloud, and then viewing of the processed data. Although imagery is often the most important information collected, there are notable exceptions for other data collection. For example, UAS were used to collect geological and hydrological data during the response phase of the mudslide that changed the course of the Stillaguamish River, killing 43 people and destroying 49 homes (Murphy et al., 2016b).

6.7 UAS to Support Construction Activities

Unmanned Ariel Systems (UASs) are being used on infrastructure construction sites by contractors for many different applications and generate valuable data that could be potentially leveraged for INDOT applications. Representative UAS construction applications include construction progress monitoring, safety surveillance, quality assurance, documentation of work zone conditions following an incident, quantity measurement, and communication with stakeholders. Illustrations of these applications are shown in Figures 6.13, 6.14, 6.15, and 6.16. The UAS data (aka deliverable) typically consists of high definition pictures and video from a standard commercial drone. Many of these constructor UAS applications directly relate to activities that are also important for INDOT, such as monitoring construction activities, quality assurance, and managing the safety of the work zone and construction project. In addition to the construction applications that directly overlap with the INDOT mission, data from construction sites could

(a) Launching UAS from a boat may be a good solution during a flood (Meis & Davis, 2016).

(b) Floodwaters may present hazards such as snakes (Herbert, 2011).

(c) If there is a large area to be covered, a manned aircraft may be a good solution (Watkins, 2005).

(d) Launch and landing sites must consider hazards from downed pwer lines and other storm damage (Crew, 2017).

Figure 6.12 Launch and landing site considerations during an emergency.

Figure 6.13 Construction progress and inspection (Winfield, 2018).

also be utilized for other INDOT applications beyond the construction phase. INDOT activities such as inventory of INDOT assets, classification of plant species, and communication with the public are just a few examples of how the data generated by construction contractors can be leveraged for INDOT use. This section

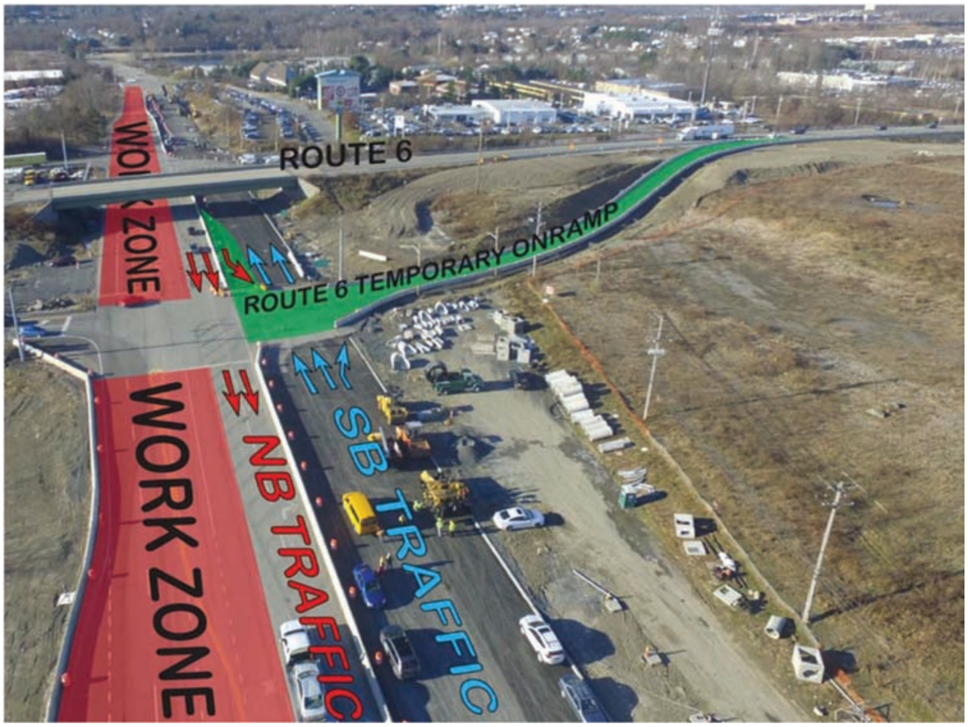


Figure 6.14 UAS work zone information (Monroe-Woodbury Central School District, 2018).

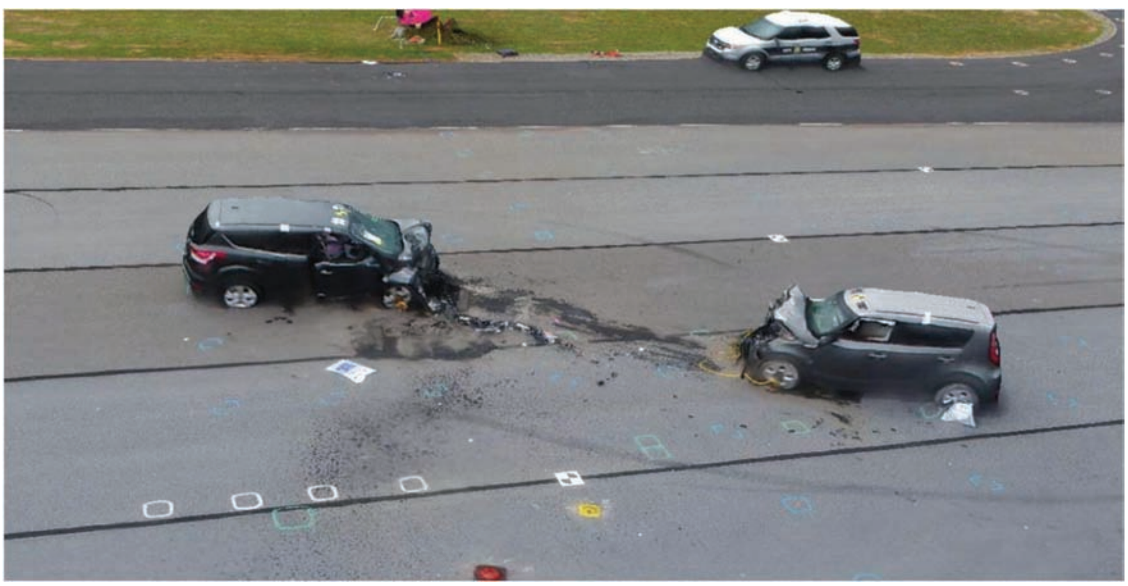


Figure 6.15 UAS work zone incident imagery (NCDOT, 2017).

reviews the potential UAS applications that benefit both contractors and DOTs, examines the use of the data for applications unique to INDOT, and presents results of a survey regarding UAS with responses from construction professionals.

6.7.1 Application

The construction industry utilizes UAS technology for numerous applications (Irizarry et al., 2017; Li & Lui, 2019) and is at the forefront of expanding commercial UAS use in the private sector (Hensel Phelps, 2019). Data generated by these contractor led activities supports a number of DOT information requirements. The UAS applications discussed generally reflect a consumer grade UAS equipped with a high definition camera, and in some cases GPS and software processing to provide a georeferenced image. This reflects the kind of UAS commonly owned and operated by a construction firm. There are numerous new technologies being employed and developed for more sophisticated kinds of inspection, including LiDAR and FLIR

Figure 6.16 UAS highway mapping with Pix4Dmapper (Pix4D, 2018).

(e.g., thermal, night vision and infrared) technology. These technologies provide even more detail of the structure, and may be able to identify cracks, deformations, and delamination in structures (Seo et al., 2018). While these technologies are starting to be used on infrastructure, the major focus of this section is to identify how UAS images and videos captured during the construction process can be utilized by DOTs.

6.7.2 Lessons Learned

A literature review of UAS applications for road and bridge construction was undertaken to identify some of the most common applications based on commercial, off the shelf UAS equipment with imagery capabilities. The identified applications were used as the basis for a survey of road and bridge contractors and consultants. The construction applications identified are reviewed in the context of how INDOT could utilize the data to help achieve complementary objectives. For example, if a construction firm is utilizing UAS for progress photos of their job site, this imagery be useful for inventory analysis of INDOT assets in the area such as signs, lighting, guardrails and drainage systems. The UAS applications for road and bridge construction are listed in Table 6.6. The following sections provide a summary of each application and identify related potential opportunities for INDOT opportunities. After the discussion of individual applications, there is a brief discussion regarding the potential to integrate UAS construction data with a GIS (geographic information system) to support INDOT activities beyond construction.

6.8 Monitor Construction Progress and/or Site Inspection

Construction Application. An early application of UAS in the construction industry was to provide documentation of the progress on a construction site. Barfuss et al. (2012) reported the Utah DOT used imagery from a UAS on a parkway project to observe the construction progress, cut and fill regions (no measurements), and record the phases of construction. A survey by Irizarry and Costa (2016) identified monitoring construction project progress was one of the most useful tasks for UAS. Generating weekly aerial maps of the construction site can reduce the time spent by construction personnel having to walk the site and provide a visual record of the project (Drone Deploy, 2018).

INDOT Opportunity. These high definition images provide the constructor with information about construction progress and can also be used by the DOT to monitor the progress of the construction project and serve as a record of work completed. The aerial imagery from UAS also provides a way to inspect construction activities in areas that are difficult to get to and/or are potentially unsafe (Irizzary & Costa, 2016). For example, temporary erosion control and sediment control can be monitored via UAS to ensure

TABLE 6.6
UAS Applications for Road and Bridge Construction Projects

Monitor construction progress and/or site inspection.
Evaluate work zone to ensure safety of motorists and workers.
Document work zone after incident or accident.
Create imagery and 3D models for construction documentation and as-built information.
Estimate stockpile and excavation quantity.
Perform material tracking.
Support construction site logistics planning.
Support surveying operations.
Support communications, marketing, public information and public relations.

effectiveness (Brooks et al., 2014; FHWA, 2019a; Irizarry & Johnson, 2014).

6.9 Evaluate Work Zone to Ensure Safety of Motorists and Workers

Construction Application. Evaluating the safety of a construction site through UAS imagery has been noted by numerous studies as an effective way to help improve worker safety on the worksite (Drone Deploy, 2018; Irizzary & Costa, 2016). UAS images allow a safety manager to review large portions of the construction site quickly, safely, and effectively evaluate the work zone to ensure workers are safe from the travelling public. The contractor can also use the images to ensure the work zone is accurately set-up, which ensures motorist safety and reduces liability. The resulting images can be used to communicate potential issues related to the work zone set-up.

INDOT Opportunity. Worker safety is a concern for all stakeholders on a construction project. An accident on a construction site or in a work zone can cause many issues for all stakeholders and the project. In addition to the direct impacts of injuries and property damage, there are impacts due to lost time, project delays, reduced worker productivity, and administrative time for reporting and investigating. INDOT benefits from new technologies that help support worker safety and from timely information on the work zone configuration. Drones provide imagery that can be used to identify adjustments that need to be made to correct a potentially dangerous work zone configuration and/or to ensure better traffic flow; as well as to document the improvements. This opportunity has been well established and was documented a decade ago by Gu et al. (2011) in an early feasibility study using drones to monitor work zones with drones.

6.10 Document Work Zone after Incident or Accident

Construction Application. Mapping crash scenes with UAS has been increasingly used by law enforcement at both the state and local level. Using UAS to document the crash scene (or site of the incident or accident) is faster than conventional methods, and allows the accident to be cleared quickly, which helps prevent secondary accidents (Bullock et al., 2019). While most of the focus has been on law enforcement requirements related to this function, contractors and DOTs also may benefit from the data obtained by a UAS at the crash scene (McGuire et al., 2016; Yamanouchi, 2013). Benefits include accurate documentation of the crash scene, which is useful for insurance claims, criminal investigations, assessment of work zone configuration, review of traffic operations, and infrastructure condition such as the resulting damage to guardrail or bridge components (Bullock et al., 2019). Contractors may become involved in litigation related to the work zone incident or accident and UAS information may be helpful to provide an accurate representation of the construction site at the time.

INDOT Opportunity. The data from a crash scene is useful for the construction contractor, and also may be useful for INDOT to improve work zone safety. The images and video may be used to evaluate why the incident occurred and provide information to improve work zone design as well as train INDOT employees in work zone design and set-up. Imagery of a crash scene or incident scene support future road safety improvements and can also support activities during litigation for all stakeholders, including DOTs. As noted by Rogers (2019), video is often helpful in a legal setting to describe the incident. UAS imagery provides a much more robust context for incident or accident conditions, as compared to traditional accident reports.

6.11 Create Imagery and 3D Models for Construction Documentation and As-built Information

Construction Application. An accurate 3D model representation of an infrastructure construction project once it is completed provides information for future repair, reconstruction and inspection. 3D models of the constructed facility can also be compared to the original design to assure construction accuracy (Irizarry & Johnson, 2014). These 3D models are based on data collected with UAS and photogrammetry software processing programs and may replace or be used as a backup to traditional drawings and specifications.

INDOT Opportunity. There are numerous INDOT benefits from 3D models that extend beyond the construction phase. The georeferenced images can serve as supplemental as-built information and provide a record of infrastructure condition. Cataloging images over a period of time provides INDOT with information that may be useful for warranty issues, for illustrating best practices, and for the provision of historic information that may be useful to improve future construction and maintenance practices for road and bridge systems.

6.12 Estimate Stockpile and Excavation Quantity

Construction Application. The management of stockpiled material, such as aggregate and soil, is important in the construction process to keep the project on schedule, and to support material management, accounting, and billing. Similarly, documentation of excavation and material movement during construction provides information regarding construction progress and is important for project documentation and payments. The volume of material and the excavation of material can be determined using UAS imagery and processing with photogrammetry software that generates a 3D model from 2D photos (Arango & Morales, 2015). Accuracies are within approximately +/- 3% (Arango & Morales, 2015; Raeva et al., 2016). If more accurate measurements are needed, more sophisticated systems can be used (e.g., higher resolution cameras with more

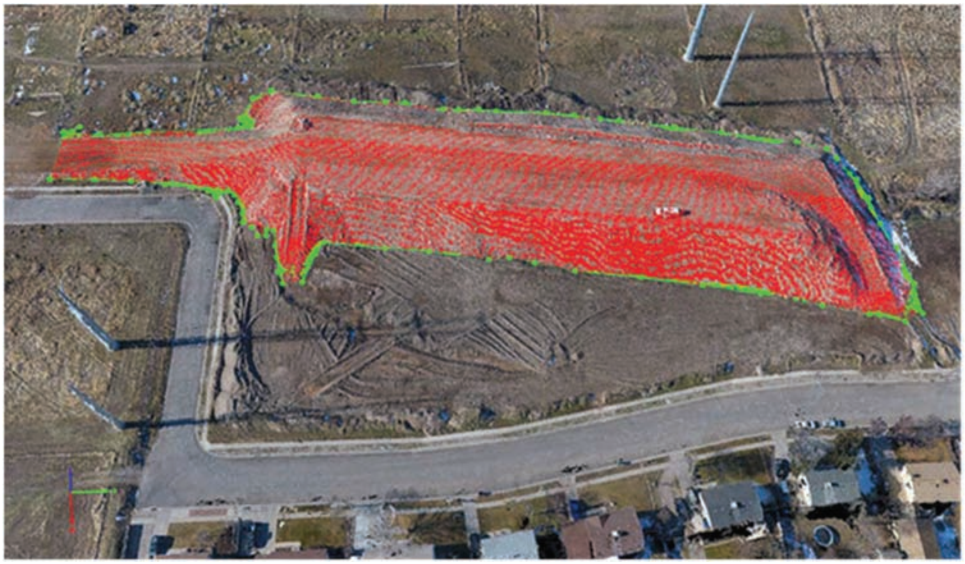


Figure 6.17 UAS stockpile estimation (FHWA, 2019c).

sophisticated use of base stations for calibration and/or LiDAR). UAS can streamline the calculation of quantities for large stockpiles, delivering higher density data in less time than traditional methods. The green color As shown in Figure 6.17 symbolizes the ground surface, while the red illustrates the quantity of the stockpile.

INDOT Opportunity. Accurate information about current material quantities volumes and current status of excavation and earth moving are important for the construction contractor and also support INDOT progress assessment, as well as payment and accounting. As noted by McGuire et al. (2016) keeping close track of stockpile inventories can help ensures that correct amount of material is provided by the supplier, can help ensure an help ensure that adequate material is available when needed and avoid material shortages or tock-outs, and may support the appropriate moisture content during construction activities.

6.13 Perform Material Tracking

Construction Application. The ability to quickly locate required materials on a construction site is important for inventory management and job site productivity. Inventory management may utilize material identification using photographs, barcodes, or Radio Frequency Identification (RFID) technology (Hubbard et al., 2015; Tatum & Liu, 2017). Commercial systems manage inventory with material tracking that may utilize UAS or vehicle-based systems. This concept is shown in Figure 6.18. Material management and tracking supports the contractor by providing timely and accurate information regarding materials that are currently in the inventory and ready for placement, as well as materials that are expected but have not yet arrived on the job site. Utilizing advanced technologies such as UAS for material tracking also reduces loss from theft and supports site security measures (Wang et al., 2014).

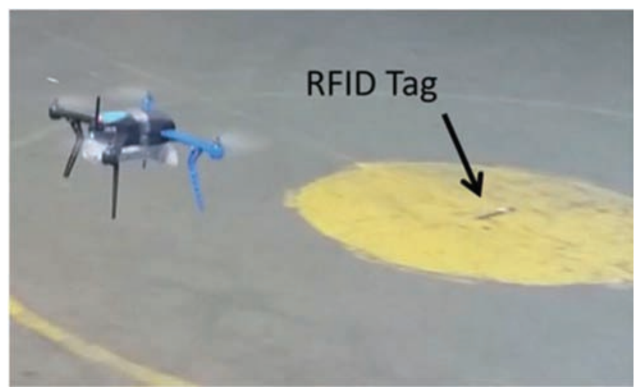


Figure 6.18 UAS mounted with RFID reader to identify RFID tag.

INDOT Opportunity. Improved material management and inventory control benefits INDOT by supporting on-site efficiency, reducing costs and delays, resulting in shorter construction times. The imagery provides a good record of inventory in case there are questions or disputes during and after construction. INDOT may also find it useful to use this kind of system to track materials for maintenance and operations at the district level (e.g., salt, sand and gravel), ensuring that the appropriate material is available when needed, and that the quantity delivered is timed and billed appropriately.

6.14 Support Construction Site Logistics Planning

Construction Application. UAS can support job site logistics and logistics planning for construction (Irizzary et al., 2016). During the pre-construction planning phase, UAS can provide detailed site information to

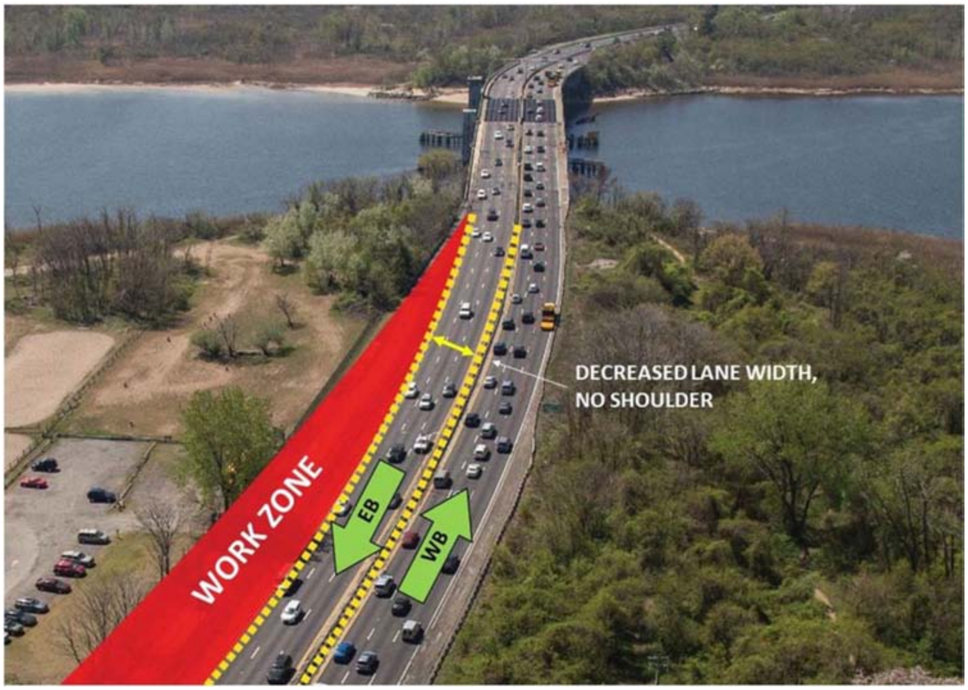


Figure 6.19 Preplanning work zone and construction site setup (Chin, 2015).

facilitate a detailed logistics plan that is tailored to the job site, including the location of material laydown, equipment location, construction site access, construction office location and parking. During the construction process, aerial images can provide information to support evaluation of material flow and worker productivity, as well as identify potential construction issues (Tatum & Liu, 2017). All these logistic related activities support a more efficient and safer worksite, which benefits both the contractor and DOT.

INDOT Opportunity. The imagery provided in the preconstruction and mobilization phase of a construction project will also support INDOT activities, such as examination and documentation of existing conditions, inspection and confirmation of the traffic control plan, (as illustrated in Figure 6.19) and locations and effectiveness of environmental controls, such as silt fences (McGuire et al., 2016). The imagery can also be used to identify potential assets (e.g., drainage structures, traffic signs, and guardrails) that may be affected by construction; these assets may need to be moved, modified, and/or protected during the construction project. The UAS imagery can help identify and provide a robust context prior to construction mobilization.

6.15 Support Surveying Activities

Construction Application. The capability of UAS to produce low cost survey maps is improving and has been aided by technology such as Global Navigation Satellite System (GNSS), Real-Time Kinematics (RTK), which enhances the precision of position data (Moser et al., 2016). While surveying may still require high-accuracy data that can be provided by more traditional survey techniques, there are numerous surveying functions, such as progress monitoring, that may use lower accuracy photogrammetry methods that leverage UAS mounted cameras, as shown in Figure 6.20. Some

(a) Surveying with traditional equipment (Arjun, n.d.).

(b) Surveying with UAS (Choi, 2016).

Figure 6.20 UAS for surveying.

advantages of UAS photogrammetry include lower cost and the ability to collect data in remote or hard to access locations (Vick & Brilakis, 2018). The reduction of survey crews on-site during construction operations reduces the exposure of survey crews to construction hazards and improves construction site safety (Vick & Brilakis, 2018).

INDOT Opportunity. Inadequate progress monitoring may contribute to poor performance in transportation construction (Vick & Brilakis, 2018). This can be addressed by enhanced monitoring, including the collection of UAS data to document work in-progress and work completed; this documentation also supports payments and payment schedules. Work progress can also be important when communicating with the public regarding construction schedules, closures, and work zone changes, as discussed in the next section.

6.16 Support Communications, Marketing, Public Information and Public Relations

Construction Application. UAS photos and video can be shared with internal and external stakeholders (Drone Deploy, 2018) to support communications, marketing, and public relations, as illustrated in Figure 6.21. UAS aerial imagery provides the construction team with visual data that is easy to interpret. Construction contractors share UAS imagery with numerous stakeholders including current and potential clients, as well as subcontractors.

INDOT Opportunity. INDOT can also use UAS photos and video to support communications, public information, and public relations. UAS photos and video can be posted on social media and DOT websites and shared with the media. UAS imagery shared with the public may be useful to provide an overview of the project and project progress (Drone Deploy, 2018). Imagery of the construction site also supports information about road detours and work zones, which may increase motorist safety. Some INDOT divisions and districts have already used drone images and videos for public information and public relations.

6.17 UAS Data from Construction Contractors May Support Other INDOT Activities

In addition to the construction applications presented above, there may be other INDOT activities that could utilize UAS data collected by construction contractors. Development of a data management system for UAS data that leverages GIS capabilities would allow data to be used for a wide variety of applications. This is illustrated by the following examples: analysis of construction traffic flow, asset inventory, and environmental management, including classification of plant species and surveillance of protected species.

Analysis of Traffic Flow During Construction. Insight into traffic flow issues during construction may be supported by UAS imagery taken by contractors during the construction process. Traffic flow characteristics such as the presence and length of vehicle queues may be visible in images collected for construction monitoring. This information may be useful for the evaluation of the safety and effectiveness of work zone traffic control plans and may be useful in analysis to increase safety and reducing motorist delays. Data shared by contractors from routine UAS flights of the construction work zone could provide valuable information for DOT traffic engineers. UAS for traffic monitoring during construction is one element of UAS for traffic monitoring, which was recognized more than a decade ago as a promising application (Ro et al., 2007). The potential capability for INDOT to leverage UAS data that is already being collected suggests the potential for access to additional information at a relatively low cost.

Asset Inventory. INDOT has many assets that need to be inventoried and maintained. UAS photographic data could be useful for both inventory and condition assessment for assets such as sign, guardrails, pavement markings, fencing, and drainage structures. UAS data has been used to support asset management by other state DOTs and agencies, which may document both location and condition information (Brooks et al., 2014). In a Utah DOT study (Barfuss et al., 2012), high resolution images were used to update the Utah DOT

Figure 6.21 UAS imagery to support communications with stakeholders (Charlier, 2016).

GIS database, including the roadway sign and highway structure inventory. UAS imagery can also be used to determine pavement conditions (McGuire et al., 2016). However, this would require high resolution information that is not easily obtained with commercially available equipment, which are typically geared for more rapid photography and ease of use rather than high resolution (Brooks et al., 2014).

Environmental Management Including Classification of Plant Species and Surveillance of Protected Species. Transportation systems have an impact on plant and animal species and their habitats (U.S. Fish & Wildlife Services, 2018), INDOT plays an important role in the environmental stewardship through activities such as classification of plant species along roadways, as well as the surveillance of protected species during the design, construction, and maintenance of their facilities. UAS are useful for classifying plants in wetlands (Barfuss et al., 2012) which may be required by DOTs (McGuire et al., 2016), such as INDOT. Although documented in the literature, interviews with INDOT personnel suggest that there are limits to the use of UAS for wetland monitoring activities, and UAS does not preclude the need for site visits. Wildlife assessment and endangered species monitoring can also be supported by UAS (Johnson et al., 2015). Imagery taken during construction operations may help DOT personnel classify species and/or identify potential habitats of endangered species. This imagery may reduce the amount of field time required by personnel, which would potentially reduce costs associated with environmental monitoring.

6.18 Results of Survey of Construction Professionals

An online survey of construction professionals was used to provide a better understanding of how drones are being used on road and bridge construction projects. All responses were anonymous. The survey was distributed using the INDOT construction listserv, which includes construction professionals who work for INDOT, as well as constructors and consultants in the private sector who do construction work under contract with INDOT. The survey consisted of five questions and included an option to provide comments. Respondents could skip any question and stop the survey at any time, so not all questions had the same number of responses.

Approximately half of the survey respondents are currently flying drones on road and bridge construction projects. As shown in Figure 6.22, 70% of contractors using drones own their own equipment and 20% both own their own equipment and hire it out to subcontractors. Only 10% of those responding solely use a subcontractor for their drone work.

Numerous applications were discussed in the previous section. One objective of the survey was to identify how UAS are currently being used by contractors in Indiana. Table 6.7 provides a ranked list of the applications currently performed by contractors. The most common application for construction projects is imagery for communications and marketing. Other popular application include estimating stockpile quantity (ranked 2nd), and imagery for as-built information and general construction documentation (ranked 3rd).

Contractors that are using drones are interested in expanding their drone applications, and contractors that are not using drones are interested in drone applications. Drone applications identified by contractors for use in the future are shown in Table 6.8. The top application for future use is using drones to document the construction work zone after an incident or accident; this reflects widespread interest, and the fact that relatively few contractors are currently using this application (it ranked 10th with only 10 responses for current use). Monitoring construction progress ranked 2nd for future use, followed by tracking material ranked 3rd, and evaluating safety for both the motorists and construction workers ranked 4th.

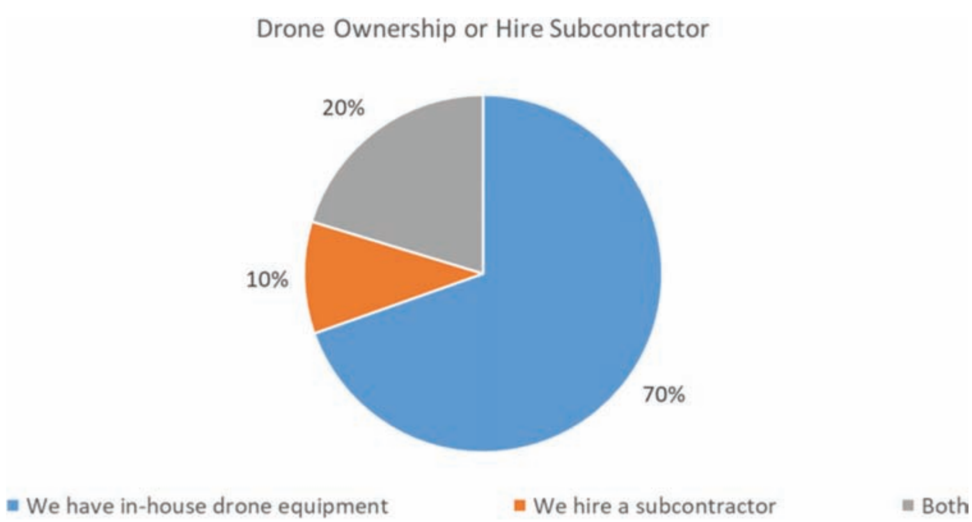


Figure 6.22 Does your company own drone equipment or do you hire a subcontractor to do your drone work? (69 responses).

Currently used applications such as using imagery for communications and marketing, ranked low for interest in future use since this use is already widely used by constructors.

Responses to two survey questions illustrate that many contractors have provided clients with drone data on past projects, as shown in Figure 6.23, and would be willing to provide clients data in the future, as shown in Figure 6.24. Considering past projects, 60% have provided clients with drone data when requested (44%) or if specified in the contract (16%); 19% have provided clients with all drone data during the project. About a fifth (21%) indicated that they never provide drone data to their client on past projects.

Concerning contractors and consultants willingness to provide drone data in the future, the majority (57%) indicated that they would provide the data if it is required in the contract. A large percentage (40%) indicated they would provide the data if they are collecting the data anyway. Only 3% indicated they would not be willing to provide data. Keep in mind that some contractors may not use drones, and depending on their area of expertise, it may be uncommon to utilize drones (e.g., a subcontractor that does chemical soil stabilization may

TABLE 6.7
UAS Applications Currently Used

Rank	Application (number of respondents using this application)
1	Use imagery for communications and marketing (58).
2	Estimate stockpile quantity (39).
3	Create imagery and 3D models to provide as-built information and construction documentation (38).
4	Monitor construction progress and/or site inspection (for example, silt fences) (37).
5	Support surveying operations (37).
6	Estimate excavation quantity (33).
7	Support construction site logistics planning (23).
8	Evaluate safety of construction site for workers (15).
9	Perform material tracking (15).
10	Document work zone after an incident or accident (10).
11	Evaluate safety of work zone for motorists (8).
12	Use for security monitoring (4).

TABLE 6.8
UAS Applications of Interest for Future Use

Rank	Application
1	Document work zone after an incident or accident (59).
2	Monitor construction progress and/or site inspection (for example, silt fences) (53).
3	Perform material tracking (53).
4	Evaluate safety of work zone for motorists (51).
5	Evaluate safety of construction site for workers (50).
6	Estimate excavation quantity (49).
7	Support surveying operations (47).
8	Create imagery and 3D models to provide as-built information and construction documentation (46).
9	Support construction site logistics planning (46).
10	Use for security monitoring (43).
11	Estimate stockpile quantity (39).
12	Use imagery for communications and marketing (34).

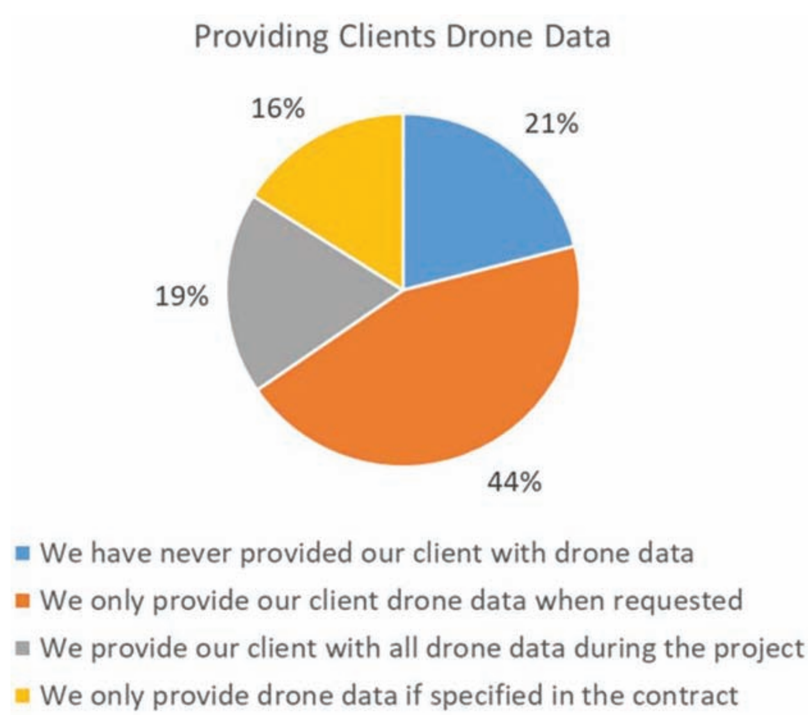


Figure 6.23 On past projects, has your company provided clients (state DOT, County, city, toll road authority, or other sponsor) with drone data? (81 responses).

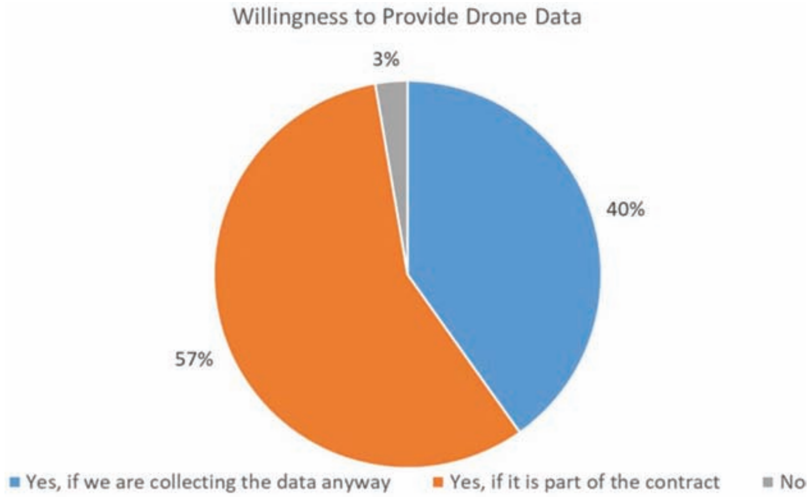


Figure 6.24 In the future, would your company be willing to provide drone data to your client? (119 responses).

have little reason to use drones). In the comments to this question, some respondents expressed concerns about liability issues and others questioned whether some of the applications would require a licensed land surveyor. There were also concerns regarding the contractor's burden and risk if drone data is included as a contract deliverables.

The comment that some work still requires a licensed surveyor raises an important point that some of the proposed applications may require licensure, expertise, or certification beyond the FAA Part 107 license. Although not relevant to this discussion about visual data products in construction, the use of some advanced UAV sensors may require advanced training for correct interpretation of results. For example, there are three levels of Infrared Thermography Certification (ITC) which may (or may not) be relevant or required when using a more advanced sensor, such as an infrared camera mounted on a drone.

Based on the survey results, drones are widely used in construction, and there is interest in an expanded use in the future. The majority of constructors have their own equipment and are using the drone imagery for communications and marketing, as well as more specialized applications such as 3D models to estimate quantities and provide as-built information. As technology advances, the use of this drone data for payments and to confirm milestones will become more prevalent.

Providing a contractual mechanism for INDOT to obtain UAS images and video captured by contractors during construction is one way to quickly integrate UAS data without requiring INDOT to own or operate UAS. Many construction firms already collect this data, and it can potentially be provided to INDOT with minimal additional effort. It is important that the data requirements be clearly defined, and that adequate consideration is given to minimizing the contractor burden and risk, since standards and procedures are still being developed.

Another important consideration is development of a data management framework to ensure that the UAS data collected can be accessed and leveraged to support all INDOT activities, as needed. For full benefit, UAS data provided to INDOT by contractors will need to be in a consistent format and stored so it is readily accessible for the many potential applications and users. FHWA has recognized that a standard format for data is a key issue, and hopefully a national standard will be forthcoming; even with a standard, there will still be a need for INDOT to identify their own database requirements. Development of a robust database that leverages GIS capabilities will ensure that all drone data can be leveraged and used to its full potential.

7. BENEFIT COST CONSIDERATIONS

UAS provide a valuable tool that may be useful to support INDOT bridge inspection safety, emergency response, and construction activities. UAS will provide a variety of benefits, (e.g., easier access to remote and hard to reach areas, good documentation of conditions, increased safety for personnel, and increased safety for traveling public) but will also incur additional costs (e.g., UAS equipment, and staff time to deploy UAS). The calculation of the ratio of the expected benefits to the expected costs provides a framework in which INDOT can compare investment in UAS with other potential investments. *One challenge with benefit cost ratios is that many benefits and costs are hard to quantify, intangible and/or do not have accurate estimates associated with deployment due to the limited application and record keeping.* This is especially true for an innovative technology such as UAS. Overreliance on the benefit cost ratio without a holistic perspective on the value of innovation may result in hesitance to implement new tools and technologies that could prove valuable; this hesitance could result in an opportunity cost to the organization.

Benefit cost information reported by other agencies varies significantly, reflecting different applications and the fact that not all benefits and costs are realized, measured and assessed in the short term. Some of the reported benefits may imply changes to federal rules regarding arms' length inspection requirements. Although the information in Table 7.1 reflects a variety of assumptions, it provides an appreciation for the range that could be expected for different applications.

An overview of expected benefits and costs for UAS implementation for INDOT is summarized in Table 7.2. Additional information for expected benefits and costs is discussed in greater detail below, with the caveat that actual costs and benefits may vary depending on a variety of factors.

Table 7.3 provides an overview of the potential costs for INDOT to incorporate drones for bridge inspection and emergency response. A four-year evaluation period is considered, reflecting a reasonable lifecycle for a drone. This framework assumes that each district would have a drone, and existing district personnel would be trained to use the drone. A significant consideration is the specific drone selected. The cost in this analysis reflects a quadcopter drone appropriate for visual bridge inspection. There are more expensive drones and additional sensors that can be purchased to expand capabilities. Tens of thousands of dollars can be spent on drones and sensors. There are also less expensive drones that can be used. For example, North Carolina DOT has reported success with $1,000 drones, which is less than half the price of the $2,200 drones specified in this analysis. The inexpensive drones used by North Carolina DOT were useful for emergency response since they fold for convenient storage and can be charged using a vehicle adapter (Murphy, 2019). North Carolina DOT used the $1,000 drones for 72 of the 112 missions flown after Hurricane Katrina (Murphy, 2019).

The country in which a drone was manufactured is becoming of increasing interest to organizations, including government agencies. This analysis does not consider the potential changes in drone price or availability due to restrictions based on the country in which the drone or drone parts originate.

Training requirements may vary, and different agencies have different perspectives and requirements on this topic. Table 6.7 includes a cost associated with training to recognize the opportunity cost of this time; however, the value of time is not included in the calculation of the benefit cost ratio since the DOT has already budgeted for this personnel expense, and no additional budget funds are required. Table 6.7 illustrates a cost for 5 days of training and practice for basic competency, including 3 days of study, 1.5 days of operator training, and 0.5 day for the exam and paperwork. No training time is included for the visual observer, since this role does not require FAA certification. Similarly, other bridge team members can serve as the operator under the supervision of the remote pilot. No FAA certification is required for the role of operator. In order to pass the FAA exam, the remote pilot must pass a two hour, 60 question multiple-choice exam (three candidate responses per question) with a minimum score of 70%. The test has a 92% pass rate, and must be renewed every two years (FAA, 2020). This cost estimate reflects coverage of information for the Part 107 exam. Some DOTs have developed additional training requirements, which is not included in this estimate. The cost for training time is based on an average bridge inspector salary of $20.35 per hour (per https://www.payscale.com, retrieved October 21, 2019); it is assumed that the cost per hour for salary plus benefits is $32.00. *It is also recommended that INDOT identify a UAS practice field in each district.* This field should have no air space restrictions and should be free of utility lines and other hazards. Although no cost has been identified for this recommendation, it is expected that this requirement can be easily accommodated using existing INDOT properties.

In terms of benefits, UAS may reduce risks to bridge inspectors and motorists. Bridge inspectors face multiple risks during field inspections. One risk for bridge inspectors is the risk of injury. Injury may be due to the bridge inspection activities or may be due to the hazards of working near moving traffic. Previous research suggests that for highway work zones, 22% of worker injuries and 43% of fatal injuries are due to motor vehicle crashes (Bryden & Andrew, 1999). Worker injury risks are reflected in the Worker Compensation Rate, which is calculated for each state each year, based on the class code of the activity. Although premiums vary, an estimate of the relative risk of different activities is reflected by comparing the rate for different class codes. The rate is expressed in dollars and cents per $100 of payroll for the class code. Table 7.4 provides rate information for Indiana for 2019. The top three class

TABLE 7.1
Reported Benefit and Cost Information

Estimated B/C or Benefit	Application	Comments	Source
B/C ≈ 9.3	Bridge inspection	UAS would only be appropriate for approximately 56% of bridges.	Oregon DOT (Gillins et al., 2018)
B/C >1	High mast pole and bridge inspection	No specific B/C ratio provided but conclusion of proof of concept is that UAS are cost effective.	(Otero et al., 2015)
B/C >1 Benefit: Additional information	Routine bridge inspections	"Cost effective way to obtain information that may not normally obtained during routine inspections."	(Zink & Lovelace, 2015)
Benefits: Additional information	Bridge inspection planning for large bridges	"Can provide important pre-inspection information for planning large scale inspections."	(Zink & Lovelace, 2015)
B/C >1	Bridge inspection	UAS can allow for tracking of delamination "UAVs could provide reliable, rapid and cost effective Bridge Deck evaluation compared with conventional methods."	(Omar & Nehdi, 2017)
B/C >1	Bridge and construction inspection	Cost and time requirements are about the same but the benefits are greater since more information is provided.	(P. Schaffer, personal communication, July 27, 2019)
Benefit: 66% cost savings *(resulting B/C would more than double)*	Steel through arch bridge with multi-girder approach spans	Hands-on inspection may still be required.	MnDOT (Wells & Lovelace, 2018)
Benefit: Save time and money	Bridge inspection	Identify problem areas faster.	MnDOT (Wells & Lovelace, 2018)
Benefit: Help locate the safest way to approach the bridge	Bridge inspection	Increase safety for bridge inspection team (reduce falls and environmental hazards).	MnDOT (Wells & Lovelace, 2018)
Benefit: Reduce duration of lane closures	Bridge inspection	Increase safety for bridge inspection team and motoring public.	MnDOT (Wells & Lovelace, 2018)
Benefit: Increase safety due to faster data collection (reduced risk for workers and motoring public)	Bridge inspection	Traditional bridge inspection requires temporary work zones, traffic detours, and heavy equipment.	(FHWA, 2019a)
Benefit: 40% savings (*resulting B/C would increase by 1.5 times*)	Bridge inspection		MnDOT as reported by FHWA (2019b)
Benefit: Efficiency 40% to 50% greater	Construction inspection	UAS reduce walking time for inspections of large construction sites and corridors (e.g., to document silt fences).	(J. Grey, personal communication, August 16, 2019)
Benefit: $83,000 in project savings	Construction cost		Utah DOT as reported by FHWA (2019c)
Benefit: Increase workforce productivity by 45%	Construction productivity		Utah DOT as reported by FHWA (2019c)
Benefit: Faster project completion	Construction scheduling and on-time completion	Project completed 25 days ahead of schedule.	Utah DOT as reported by FHWA (2019c)
Benefit: Faster data collection for survey or aerial photography	Construction surveying and project documentation		(FHWA, 2019a)
Benefit: More efficient stockpile measurement with cost 10% of GPS survey	Construction and maintenance		(FHWA, 2019d)
Benefit: Reduce surveying time by 50%	Surveying (including construction surveying)	Collected data in a week, processed LiDAR data in a week, vs. what would have taken a month with conventional surveying.	Utah DOT as reported by FHWA (2019b)
Benefit: More accurate quantity calculations	Construction quantities and payment	Support contractor payments.	(FHWA, 2019a)

TABLE 7.1
(Continued)

Estimated B/C or Benefit	Application	Comments	Source
Benefit: Efficient for routine construction inspections	Construction compliance with Clean Water Act	UAS can fly a programmed path over silt fencing after a rain event to check for sediment buildup.	(FHWA, 2019a)
Benefit: Increase safety for high-risk inspections	High-risk construction inspections	Crane or falsework construction.	(FHWA, 2019a)
Benefit: Identify problem areas with terrain mapping.	Emergency management, mitigation	Safe lives and reduce costs.	(FHWA, 2019a)
Benefit: Survey damage quickly	Emergency management, response and recovery	Supports informed decisions and efficient plan for recovery; inexpensive and fast method to survey damage.	(FHWA, 2019a)
Benefit: Monitor traffic on detour routes	Emergency management: Response and recover	Also provided information to decision makers and facilitated deployment of field personnel to appropriate locations.	(Murphy, 2019)

TABLE 7.2
Summary of Expected Benefits and Costs for INDOT

Application	Benefits	Cost Considerations
Bridge safety	*Increase safety:* Identify potentially hazardous conditions on bridge or in bridge environment Identify climb points Identify inspection procedures Ensure tools needed for safe inspection are readily available Reduce lane closure time, increasing safety of team and public Reduce road crossings by bridge inspection team Overall: reduce risk exposure for bridge team by substituting UAS time with time on bridge (when appropriate) Reduce risk to traveling public due to reduced inspection time on bridge in field	Costs vary significantly depending on capabilities (e.g., collision avoidance, quality of images). Entry level UAS with image capability only will provide significant benefits at a low cost and more advanced sensors can be integrated in the longer term.
Construction	Reduce inspection time for construction progress and milestones Increase public information during construction Document work zone traffic control for quality control and in the event of a crash Document pay items (e.g., excavation) Document compliance with environmental controls (regular and special inspections) Improve quality control (e.g., temperature of pavements using infrared on UAS) Reduce surveying time	Costs vary; costs will be known prior to deployment if contracted as a separate line item.
Emergency management	Increase safety for responding team Allow safe estimate of damage Document damage for federal reimbursement	UAS cost may be as low as $1,000 for a portable unit; battery can be charged by plugging into car with an inverter (Murphy, 2019).

codes in Table 7.4 (5037, 5040, and 5506) reflect field activities related to roads and bridges. The average workers comp rate for these three activities is $4.90. This rate is an order of magnitude higher than the workers comp rate for field UAS (code 8720) and the associated data processing (code 8810), which have an average value of $0.48. Even if utilization of UAS does not reduce the overall time for the bridge inspection, if it shifts activities to lower risk categories, then the overall safety for bridge inspection is increased. For example, if utilization of UAS allows inspectors to spend less time on the bridge or near moving traffic, then overall safety is increased.

Based on reports of UAS by other agencies, it is assumed that utilization of a UAS will increase safety by reducing the exposure to hazards by 50%, since the hazardous duties in the field can be shifted to less hazardous UAS field time and time reviewing UAS video in the office. This is reasonable and may be a conservative assumption. Kansas DOT studies even suggest the possibility of complete bridge inspections

TABLE 7.3
Estimated Cost for UAS for Bridge Inspection Safety and Emergency Response

Year	Description	Quantity	Cost	Total
1	UAS DJI Mavic 2 Enterprise $2,200	10 (1 per district with bridge team plus 3 extra)	$2,200 per UAS	$22,000
	Parts and Repair (per year)	1	10% of capital	$2,200
	Training for New Remote Pilot	10 (1 person per district plus 3 extra)	$1,000	$10,000
	Time to Train New Remote Pilot[1]	5 days (40 hours) for each of 10 people 3 day course 1.5 day operator training 0.5 day exam and paperwork	Average $32/hr (salary plus benefits)	$12,800[1]
	Exam	10	$150	$1,500
	Total Cost Year 1			*$35,700*
2	UAS Parts and Repair			$2,200
	Total Cost Year 2			*$2,200*
3	UAS Parts and Repair			$2,200
	Training for Recertification	10 remote pilots	$500	$5,000
	Time for Recertification Training[1]	10 remote pilots 2 day (16 hours) for each remote pilot 1.5 day training 0.5 day exam and paperwork	Average $32/hr (salary plus benefits)	$5,120
	Exam	10	$150	$1,500
	Total Cost Year 3			*$9,700*
4	UAS Parts and Repair			$2,200
	Total Cost Year 4			*$2,200*
	Total Cost Years 1 to 4			$49,800

[1]Training time is recognized but not included in the B/C, since it does not require separate funds to be allocated.

TABLE 7.4
Indiana Worker Comp Rate Data

Class Code	Description	Indiana Rate[1]	Average Rate
Field activities in the road and bridge environment			
5037	Painting metal structures over 2 stories in height (including bridges).	6.33	4.90
5040	Iron or steel erection frame structures (including metal bridges).	4.35	4.90
5506	Street or road construction: paving or repaving.	4.03	4.90
Activities related to UAS inspection			
8720	UAS operations, one component of inspection of risks for insurance or valuation (not otherwise classified, includes safety engineers).	0.83	0.48
8810	Clerical office employees in computer or office work, includes wages paid to construction employees if work is exclusively office work.	0.12	0.48

[1]Indiana Rate as of January 1, 2019 as published by the National Council on Compensation Insurance (NCCI, 2018).

performed by UAS in as little time as an hour (Mcguire et al., 2016), although this would not be consistent with current FHWA rules for arm's length bridge inspection.

Although most researchers do not suggest such dramatic reductions in inspection time in the near term, other UAS researchers do confirm the capability of UAS to reduce the duration of field activities for bridge inspection, especially since the cost to inspect a bridge may add up quickly when the cost of road closures and traffic re-routing are considered. MnDOT researchers found that although a hands-on inspection may still be required, pre-planning with a UAV can save both time and money by identifying problem areas and helping to locate the safest way to approach the bridge. With a course of action readily identified, the traffic closures are for much shorter periods of time and cost much less (Wells & Lovelace, 2018).

In addition to the safety risk for the bridge inspection team, the motoring public realizes costs associated with bridge inspection activities. These costs include increased delay and an increased crash risk due to the temporary work zone required for inspection activities. The work zone may include traffic control, a reduced shoulder width and/or a reduction in the number of traffic lanes.

In terms of delay, historically, work zones account for approximately 10% of all congestion (Cambridge

Systematics & Texas Transportation Institute, 2005) and approximately 24% of non-recurring freeway delay (Chin et al., 2004). Bridge inspection work zones are a relatively small portion of all work zones, and the contribution of bridge inspection work zones to overall motorist delay has not been quantified.

In terms of increased crash risks, the crash risk associated with work zones is significant. One study found that crash rates in freeway work zones were 21.5% higher than during the pre-work zone period, with non-injury crashes increasing 23.8% and injury crashes increasing 17.3% (Khatttak et al., 2002). Other research found that state highways and rural interstates are more vulnerable to work zone crashes (Chambless et al., 2002; Pigman & Agent, 1990; Yang et al., 2015).

Since crash costs are significant, reducing the duration of the work zone is significant. The estimated cost of a work zone crash varies. At the low end, Sorock et al. (1996) reported an average cost of $3,687 for a work zone crash in 1996; this is equivalent to approximately $6,000 in 2019. The cost in 2019 is estimated using the Bureau of Labor Statistics CPI inflation calculator (Bureau of Labor Statistics, n.d.) to adjust the value from January 1996 dollars to January 2019 dollars. Other research has identified much higher costs for work zone crashes: $7,673 for a property damage only (PDO) and $116,375 for an injury crash, as reported in 1996 dollars by Mohan and Gautam (2002). Converting these costs to current dollar values, the equivalent costs for 2019 would be approximately $12,750 for a PDO crash, and $193,000 for an injury crash. These values reflect direct costs, and do not consider the indirect costs, which may be 4 to 17 times the direct costs (Mohan & Gautam, 2002). Other research confirms the high cost of work zone crashes, with the following estimates of the comprehensive cost in 2010 dollars: $542,533 for incapacitating crashes, $147,536 for non-incapacitating crashes, $86,900 for possible injury crashes, and $10,956 for PDO crashes (Coburn et al., 2013). These costs were significantly higher than the inflation-adjusted FHWA default values. The cost of incapacitating injury crashes was 105% higher than FHWA values, non-incapacitating injury crashes were 35% higher, and possible injury crashes were 50% higher than the inflation adjusted FHWA default values (Coburn et al., 2013). The values increase to $630,227 (incapacitating injury), $171,383 (non-incapacitating crashes), $100,946 (possible injury) and $12,727 (PDO) in 2019 dollars.

To provide another context for work zone crash risks, consider the prevalence of injuries and fatalities for construction workers relative to injuries and fatalities for motorists traveling through the highway work zone. According to research by Mohan and Gautam (2002), 30% of the injuries involve workers, and 70% of the injuries involve motorists traveling in the work zone. More recently, the CDC (2017) reports that each year there are 121 worker fatalities (14%) and 750 motorist fatalities (86%) due to work zone crashes. Of the fatally injured workers 14% were government workers, equally divided among state and local governments (CDC, 2017).

Additional information about risks to the bridge inspection team is provided in Table 7.5. Bridge inspectors are vulnerable to the two most frequent causes of occupational death: transportation incidents (2,077 fatalities representing 40% of all fatalities) and fatal falls (887 fatalities representing 17% of all fatalities) (Bureau of Labor Statistics, 2018). The most common are workplace injuries and illness, which may be due to falls from height, sprains and strains due to slips, trips and over-exertion, and illness and injuries due to a wide variety of environmental hazards that include insects and wildlife, as well as poison ivy.

One risk to bridge inspectors due to insects is Lyme disease, which is caused by deer ticks and mosquitos. This is an increasing risk in Indiana. 440,000 people are diagnosed with Lyme disease each year (Cameron, n.d.). Recent reports from IU found that the number of cases of infectious disease from ticks, fleas, and mosquitoes in Indiana have tripled since 2004, and in 2016 there were 127 cases of Lyme disease (Rudavsky, 2018).

In Indiana, the rate of nonfatal injury and illness per 100 workers was 2.4 for state workers, 2.8 for construction, 4.7 for transportation and warehousing, and 5.2 for local government (Indiana Department of Labor, n.d.). It is difficult to estimate the injury and accident rate for bridge inspectors, due to the relatively low number of inspectors, and the work group does not have a separate designation for North American Industry Classification System (NAICS), which is used to identify the industries and sub-industries for workplace injury and illness data.

The estimated cost of a worker injury or illness in 2017 was $39,000 when a medical consultation was needed, and the cost per fatality that results from a workplace injury is $1,150,000 (National Safety Council, n.d.). These costs include medical expenses (21% of the total cost), wages lost and lost productivity (31% of the total cost), employer costs (15% of the total cost) and administrative costs (32% of the total cost). These costs imposed a burden of $1,100 per worker in 2017, which reflects the overall burden to the workforce, but not the average cost of a work-related injury.

Injuries due to roadway incidents is the leading cause of work-related fatality and the seventh leading cause of injury with days lost from work (Reeve et al., 2019). Transportation workers are especially vulnerable to these injuries, but their vulnerability may be reduced by reducing their field time by using UAS. UAS may be especially useful during emergency response, when conditions may be uncertain. Use of UAS may also make workers less vulnerable to injuries and accidents that are related to fatigue (National Safety Council, 2020).

Table 7.6 provides a summary of the estimated benefits related to safety that would be realized if INDOT implements UAS for regular bridge inspections. These estimated benefits reflect use of UAS for the inspections

TABLE 7.5
Sample Risks to Bridge Inspectors Working in the Field

Risk		Implications	Source
Traffic accidents	 (Opiela et al., 2006)	5.5% of disabling workplace injuries and 121 work zone fatalities in 2018 were due to traffic accidents.	(Liberty Mutual, 2018)
Falls	 (FHWA, 2012)	Falls are the leading cause of worker fatalities and account for almost 30% of the total workplace injury burden. Workplace falls cost $17.1B in direct costs in 2018.	(Liberty Mutual, OSHO, n.d.a.)
Sprains, strains and overexertion and slip or trip without fall	  (FHWA, 2006)	27.3% of disabling workplace injuries cost $16B in 2018. Unstable banks, gravel on the roadway and other environmental hazards may increase the risks of sprains, strains and overexertion.	(Liberty Mutual, 2018)
Environmental hazards due to insects, wildlife and vegetation (e.g., Lyme disease)	 (CDC, 2020)	Environmental hazards include insects, wildlife and vegetation. One example is Lyme disease, which cost an average of $16,000 annually per person (approximately half of this is due to lost productivity).	(Cameron, n.d., Zhang et al., 2006)

on half of INDOT's bridges (presumably only the larger ones) and reflect the fact that INDOT correlated with a reduction in hazard exposure for both the INDOT bridge inspection team and motorists.

The estimated values seem very reasonable and very conservative when considered in the context of the cost of worker injuries discussed above. Similarly, the use of six drones for the inspection of 633 bridges is reasonable, with each drone serving about 100 bridges, and being used for one hour on each bridge. This correlates to 400 hours of use over the proposed four-year life-span and analysis period. This is consistent with drone

TABLE 7.6
Estimated Benefit for UAS for Bridge Inspection Safety

Component of Estimated Benefit	Expected Impact (per year)
Bridges	*Number of INDOT Bridges: 5,766* Bridges that would not utilize a drone: 5,662 Average field inspection time without UAV: 2 man-hrs Bridges that would utilize drone for inspection: 1,162 104 inspected every 12 months Average field inspection time: 2 man-hrs No change in inspection time 50% reduction in bridge team hazard exposure due to drone use 1,058 inspected every 24 months (529 of these inspected every 12 mo) Total 633 bridges inspected with UAV every 12 months Average field inspection time with UAV: 4 hrs (2 hours for 2-person team) UAV for special bridges (include special detail inspection, bridges with more than two lanes in each direction, scour critical bridges, and those with routine frequency of less than 24 months)
Decrease exposure to injures for bridge team by reducing hazard exposure by 50%	*2 man-hrs * 633 bridges = 1,266 man-hrs reflects the reduction in hazardous field time by 50% (reflecting half of the two-hour inspection time for a 2-person team)* Value of reduced exposure to worker injury based on worker's compensation rates in Table 6.11: (1,266 hrs * $32/hr) / $100 * ($4.9 – $0.48) = $1,791 This represents 15% of work zone injuries according to previous research by CDC (2017).
Decrease motorist exposure to work zone crashes	*Value of reduced injuries to bridge inspection workers is $1,133 per year* If this reflects 15% of the work zone injuries, then motorists will realize a reduction in injury risk of $10,147 (reflecting 85% of the work zone injuries). This estimated is based on exposure to fatality events per CDC (2017) This generally correlates to the elimination of one possible injury accident every ten years based on the cost of crashers per Coburn et al. (2013) This correlates to a reduction in property damage for work zone crashes of $2,131 (for every $1 of injury, there is a motorist cost of $0.21 for PDO crashes) Total value of reduced exposure to motorist injury and PDO crashes is $12,278 per year Do not consider reduction in fatal crashes since it is a rare event
Decrease motorist delay	*Financial value of reduced motorist delay not included in analysis*
Total	*Value of reduced exposure to worker injuries and motorist traffic injuries and PDO crashes is estimated to be $14,068 per year*

TABLE 7.7
Estimated Benefit/Cost for UAS for Bridge Inspection Safety (four year period)

Year	Expected Benefit ($)	Expected Cost ($)	Estimated B/C
1	14,068	33,950	
2	14,068	1,540	
3	14,068	10,942	
4	14,068	1,540	
Total	*56,272*	*49,800*	*1.1*

life expectancy reports of 800 hours for a Phantom (DroneU, n.d.)

Table 7.7 provides an estimated benefit cost ratio (B/C) for using UAS for bridge inspection. The benefits quantified reflect only the benefits related to safety, specifically the reduced exposure to inspection team workers to field hazards and the reduced exposure of motorists to injury and PDO crashes. There may be additional benefits related to reduced delay and increased capabilities that are not quantified; these additional benefits would increase the B/C. All values reflect 2019 dollars (considering the net present value, this B/C shown reflects an inflation rate that is the same as the real interest rate for the four year analysis period).

The benefit cost analysis indicates that the proposed use of UAS for bridge inspection safety would provide a benefit cost ratio great than one and would therefore be an appropriate investment.

INDOT is directly responsible for the regular inspection of over 5,766 bridges. Our analysis conservatively estimates the benefits that would accrue if UAS are used for 633 of these, which is approximately 10%. This is a conservative assumption, since other DOTs have suggested that UAS may be useful and provided benefits for approximately half of bridges. For example, Oregon DOT estimates that UAS would be useful for 56% of bridges (Gillins et al., 2018). The percent of bridges would depend on the bridge characteristics, which would vary depending on the road network and geography. Bridge inspection requirements vary depending on bridge size, condition, and structure type; UAS may not provide much safety benefit for smaller bridges. Although not quantified, it is likely that local bridge inspections contracted by the counties would also benefit from the integration of UAS. In many cases, local agencies adopt INDOT policies for successful programs. The benefits associated with UAS for local bridge inspections could also be significant.

8. OTHER CONSIDERATIONS

8.1 Hazard Assessment

As is the case for any change in operational procedures, integration of UAS may present potential hazards and risks that should be carefully considered prior to implementation, and in a systematic way upon implementation.

A hazard is the potential to cause harm, and risk is the likelihood that a harmful event will occur. Since UAS are a relatively new tool, there is a lack of data in the highway environment. Analysis of data from other sectors is useful to understand the likely UAS hazards, where were defined by Belcastro et al. (2017) as follows:

- UAS flight control issues: a failure of a component of the flight controls. Flight controls are the propellers, GPS, or any other feature that aids directional movement in flight. Flight control risks can be mitigated through cleaning and proper storage of the unit.
- Wind shear: a change in wind velocity at right angles to the direction of the wind. Mitigation procedures would be self-righting systems and scheduling flights on days with optimal weather.
- Propulsion: a variance in the directional force that results in less than or more than the amount needed to complete a task. An example would be not enough lift occurring from the propellers to lift an UAS off the ground. A mitigation to propulsion issues would be checking battery levels before, during, and after flight, constantly making sure there is enough battery for return to home flight.
- Lost link: a lost link refers to loss of communication between the drone and the control system; a lost link may be caused by interference from other signals, or if the drone is being flown under the bridge or another location that physically blocks the signal. Risks associated with lost links are mitigated by programming that has the drone return to home or descend to the ground or proceed to a designated location in the event of a lost link.

These are a few examples of problems that cause incidents or accidents. Incidents are any occurrence, other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations (FAA, 2010). FAA and NTSB have different requirements for accident reporting. FAA requires that the remote pilot report within 10 days any serious injury or loss of consciousness, or property damage more than $500 (other than damage to the UAS) (FAA, 2016; Small Unmanned Aircraft Systems, 2016).

Based on an analysis of reported UAS mishaps between 2010 and 2015, flight control issues caused 15% of incidents and accidents, and follow undetermined causes (32%) as the leading cause of incidents and accidents (Belcastro et al., 2017). Flight crew problems were the next highest cause, followed by propulsion, lost links, and software (Belcastro et al., 2017), as shown in Figure 8.1. Figure 8.1 illustrates that most reported mishaps are incidents rather than accidents, which implies lower severity. This data overstates the hazards of UAS operation, since all of the data reflects operations prior to Part 107. Increased regulations, as well as improved technologies (UAS control, obstacle avoidance, etc.), make UAS safer than ever. Moreover, Belcastro et al. (2017) noted that there are more injuries, incident, damage and fatalities for hobbyists and amateur users of UAS.

The risk categories identified by Belcastro et al. (2017) include injury to personnel, property damage, and traffic disturbance. Most of the incidents involved collision with an object, including collision with terrain (20%), obstacles (19%), person (5%) and ground vehicle (4%); other incidents involved uncontrolled descent (13%), a crash in the landing area (13%), return to base (10%), flight termination (6%), a landing without further incident (5%), and airspace conflict (3%) (Belcastro et al., 2017).

Following Part 107 rules will reduce the risk associated with flying drones. The use of preflight inspections, a visual observer, compliance with visual line of sight requirements, and the limits on flight over people and busy traffic will all reduce risk. The preflight inspection reduces risk because it ensures a check of transmitters, receivers, sensors, wings or propellers, and battery life.

There are risks associated with drone use, and there is a potential for injury, as evidenced by reports since the research by Belcastro et al. (2017). In one incident, a drone broke a car window and a child in the back seat was injured (Satterlee, 2018). In another incident, a civilian drone caused a helicopter crash (NTSB, 2017). In both of these cases, the pilots were hobbyists and did not have a license under Part 107. Although the consequences of inappropriate and dangerous drone use can be serious, risks of drone use could be lower than the risks of driving a vehicle, or many other activities that are part of everyday life, and an accepted component of work place duties. This is emphasized by the fact that there were over 100,000 people registered with a Remote Pilot Certificate (FAA, 2018b) and over 100,000 registered drones (878,000 hobbyist drones and 122,000 for commercial and government use) (Flight Safety Foundation, 2018).

The risks are also affected by drone weight, operating speed, and operating conditions. Part 107 addresses all drones up to 55 lbs, but drones used by INDOT are likely to be much lighter. North Dakota DOT uses the DJI Mavic 2 Pro (NDDOT, 2019), which has a takeoff weight just over 900 grams, about 2 lbs (DJI, n.d.d). Other common drones used by public agencies include the DJI Matrice 600 Pro and the DJI Inspire 2. The

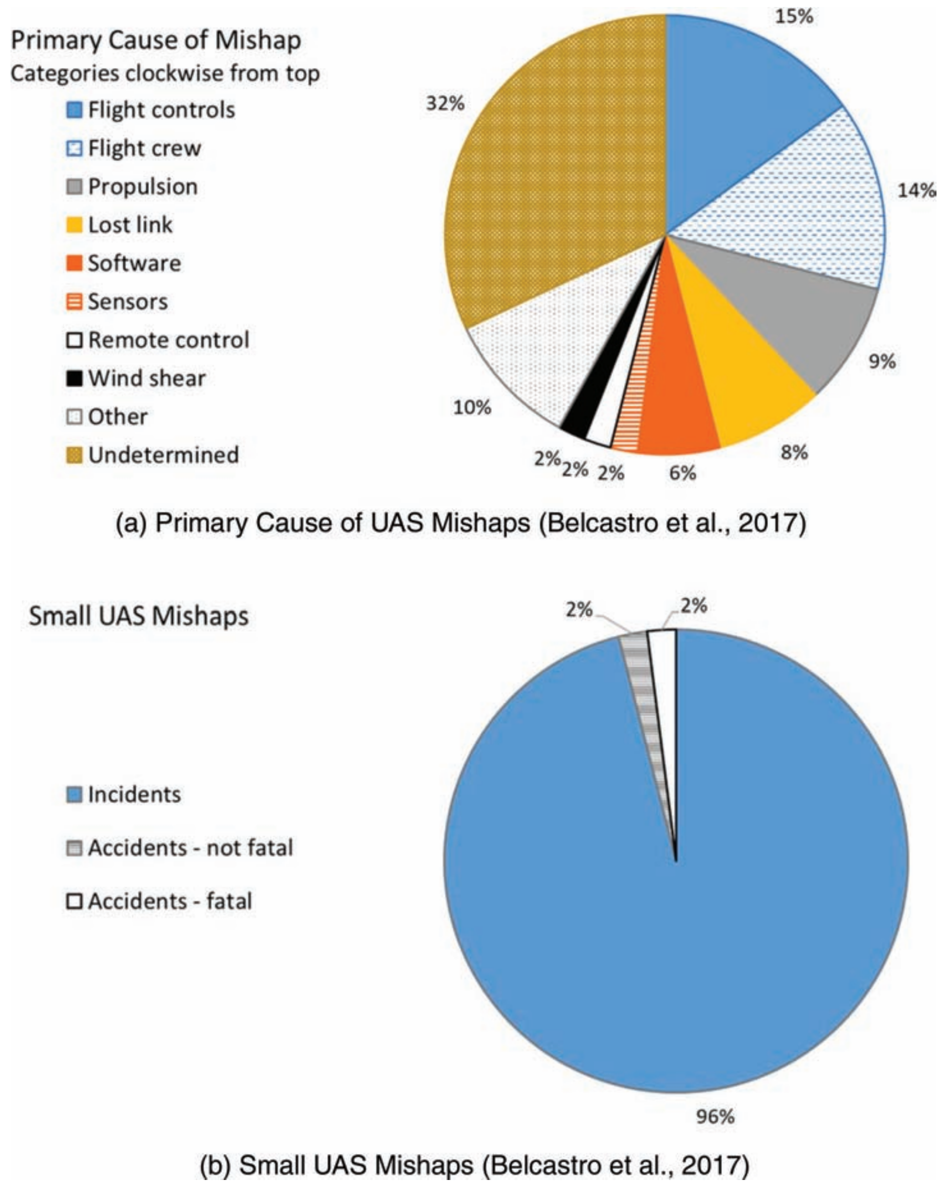


Figure 8.1 Characteristics of UAS mishaps.

Inspire 2, used by the Indiana State Police, has a maximum takeoff weight of 4,250 g (9.37 lbs) (DJI, n.d.b). The Matrice 600 Pro has a maximum takeoff weight of 15.5 kg (34.17 lbs), with configuration options that may reduce the weight to 9.5 kg (20.94 lbs) (DJI, n.d.c).

State DOTs have also identified additional procedures that minimize the chance of encountering hazards. Georgia DOT employees have meetings before and after the flight to discuss the mission, at the meeting before flight, they also establish a home base for the UAS to return to (Irizarry & Johnson, 2019). The home base is a bright orange miniature helicopter pad that is laid upon a flat surface. Georgia DOT also uses a router to extend the range of the transmitter as a standard procedure (Irizarry & Johnson, 2019). TxDOT addresses risk mitigation in a number of ways, including Project Risk Assessment (PRA), a Health and Safety Plan, an In-Flight Emergency Plan, and a Downed Aircraft Recovery Plan (DARP), as described below (TxDOT, 2017).

- *Project Risk Assessment (PRA).* The PRA is conducted prior to drone operation and is used to determine whether the operation requires the approval of the UAS Coordinator. Considerations include the area around the planned operation, airspace classification, proximity of airports or heliports, roadway traffic volume and speed, the potential for driver distraction, and the potential to use other technologies that may be better suited for the task.
- *Health and Safety Plan.* This plan is used to identify potential hazards in the area where the drone will be flown, mitigate risk, and plan for response if an incident occurs. This plan requires every member of the flight crew to know the directions to the nearest emergency room and how to describe the area to a 911 operator. It is

suggested that regular check-ins be implemented for areas without cell phone coverage and requires the knowledge of a back-up area that has adequate cell phone coverage. This plan reinforces the dangers of displaying signs around high density traffic areas, and the danger of trying to catch or handle a drone while the propellers are still spinning. Other risks identified include standing beneath the drone, standing in the path of a fixed wing drone takeoff or landing area, and the dangers of liquid fuel, and batteries that can explode or catch fire.

- *In-Flight Emergency Plan.* The In-Flight Emergency plan is a comprehensive plan that provides steps for responding to emergencies and incidents. Recovery steps are provided for partial or total loss of aircraft power, drone flyaways, bird strikes, airspace encroachment, erratic behavior, fixed object strikes, outside interference, and nearby emergency response. The responses range from hoping it does not hit anything while planning a recovery during a total loss of control, to repeatedly pushing the return to home button and watching out for an aircraft fly-away. After the response and recovery, the remote pilot must determine whether the incident or accident needs to be reported to the UAS Coordinator, FAA and/or NTSB.
- *Down Aircraft Recovery Plan (DARP).* The DARP should be implemented in the event that the drone crashes into an area of concern and the plan aligns with the response outlined in the In-Flight Emergency Plan. Generally, if a UAS crash lands in a hazardous area, the flight crew should not retrieve it unless they are instructed to do so by an emergency responder. Any area that "could reasonably be expected to endanger" the persons recovering an UAS is considered hazardous (TxDOT, 2017). Examples of hazardous landings include entanglement with any utility lines, on high volume roadways and railways, in areas near cliffs or sinkholes, in water more than five feet from the bank, and on private property or fenced-in government property. No drone will be recovered until the emergency response has been completed.

Oregon DOT has also implemented procedures to ensure safety while using UAS for bridge inspections. Examples include the following (Gillins et al., 2018).

- Restrictions on the use of cell phones for purposes other than communications needed UAS operation during flight, such as Air Traffic Control.
- Procedures for PIC notification if the VO loses sight of the aircraft. If the drone immediately reenters line of sight, the flight may continue. If the drone stays out of sight, or if the PIC loses contact with the VO, they must begin lost link procedures. This procedure can be return to home or immediately land.

Recently, North Dakota DOT received a waiver for flights over people (NDDOT, 2019). The waiver applies specifically to DJI Mavic 2 with a ParaZero SafeAir parachute attached (NDDOT, 2019). This waiver was awarded as part of research to advance safe operations and expand regulations (NDDOT, 2019).

To reduce the potential for driver distraction due to roadside drone use, some DOTs post signs where drones are being used. TxDOT posts a surveying ahead sign followed by a Drone inspection sign (TxDOT, 2017), as shown in Figure 6.7. Others are concerned that these signs may increase distraction, if they cause drivers to look for the drones. Reports from with UAS professionals indicate that this has not been a problem (e.g., conversation with Ryan Aspy of BrightSpark Aerial Imagery and Andrew Wall of TopShot Aerial Photography on October 25, 2019).

8.2 Data Management

Drones can collect video and still images, as well as georeference data. It is valuable for an agency to develop standard procedures for data collection and data management to ensure others can easily find and view the data they need, and to archive data for historical purposes. This includes the need to document conditions in the event of litigation (Murphy et al., 2016b).

A comprehensive data management policy can also address policy issues such as how data can be shared with other emergency management partners, and who has authorization to access and share data. Data management can also support a common framework for data records to support interoperability of equipment, and seamless access to software and data files created by different UAS software programs (Murphy et al., 2016b). Ideally, a successful data management system will ensure compatibility not only with different software, but also with different versions of software as capabilities increase. INDOT, like all agencies, should recognize that data curation presents significant challenges, and encompasses issues related to data processing, data transmission and chain-of-custody, and data storage and dissemination (Murphy et al., 2016b). Data management is critical for UAS data collected during disasters (Murphy et al., 2016b), data that is used to support regular operations, and for agencies that are developing UAS programs.

8.3 Public Information

Drones can provide information to support public information, and public relations for the DOT. INDOT has successfully used drone footage to illustrate construction activities when roads are closed, and to document construction for the large scale projects, such as the construction of the I-69 corridor, as shown in Figure 8.2. Drone video and still images can be provided to news stations, and published on INDOT's social media accounts, including YouTube, Twitter, Facebook, and Instagram.

INDOT may find increasing applications for images and videos that are collected by UAS, including UAS owned and operated by INDOT employees, as well as UAS video and images obtained through contracts with construction companies and other contractors.

8.4 Training

Drones can provide information to support agency training, and to support maintenance of institutional knowledge as long time employees retire. Experienced bridge inspectors (or other professionals) can be video-taped with drones, and then can provide the voice over narrative to explain the procedure that is being executed. Video and still images collected with drones can also be used to illustrate common, as well as unusual bridge conditions, for training purposes. A still photo from one of INDOT's videos is shown in Figure 8.3.

(a) Video and images collected with UAS can be used to let the public know what is going on during road and bridge closures (INDOT, 2019).

(b) UAS can be used to collect video for large scale corridor projects such as this image from video of I-69 (INDOT, 2015).

Figure 8.2 UAS can support public information.

Figure 8.3 UAS can support training (INDOT, 2018).

9. CONCLUSIONS AND FUTURE RESEARCH

UAS have already had a significant impact in the construction, operation, and maintenance of our nation's infrastructure. UAS will become an increasingly valuable tool in the future, since there are numerous potential applications for UAS. DOTs and other transportation agencies need to prioritize UAS applications for strategic implementation. Prioritization should consider the many possible applications in the context of agency priorities, competing interests, finite funding resources and personnel constraints. The framework presented in this paper can assist DOTs and transportation agencies in their decision process, as well as enhance communication and coordination. The proposed framework focuses on a quantitative and qualitative approach that prioritizes the (1) stakeholder Input, including stakeholder acceptance and ease of adoption, (2) benefits, and (3) technical feasibility. The method presented could be tailored to reflect individual agency goals by adjusting the assessment areas (e.g., separate agency benefits and public benefits), and by adjusting the weighting of for the assessment areas based on agency priorities.

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APPENDICES

Appendix A. Additional References and Part 107 Training Resources

Appendix B. Supplemental Accident Reporting Information (FAA and NTSB)

Appendix C. Summary of Topics Addressed by State sUAS Policies

Appendix D. Glossary of Terms and Acronyms

Appendix E. Public Information from DOTs Regarding Emergency Response, Bridge Inspection, and Contractor Provisions (e.g., for construction)

Appendix F. Summary of Findings from Survey of Bridge Inspectors

APPENDIX A. ADDITIONAL SOURCES AND PART 107 TRAINING RESOURCES

FAA Guidance on sUAS
Small Unmanned Aircraft Systems (sUAS). Advisory Circular (AC) 107-2. June 21, 2016.
https://www.faa.gov/uas/media/AC_107-2_AFS-1_Signed.pdf

14 CFR Part 107 Legislation
https://www.ecfr.gov/cgi-bin/text-idx?SID=d9f8b66f20ae284898fdc99b88b92924&mc=true&tpl=/ecfrbrowse/Title14/14cfr107_mai n_02.tpl

FAA Summary of Part 107 Legislation
https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=20516
https://www.faa.gov/uas/media/Part_107_Summary.pdf

FAA UAV Registry
https://faadronezone.faa.gov/#/home

FAA Certification Resources for a Remote Pilot Through Part 107
The exam for certification through Part 107 requires that you successfully complete a 60 question exam in 2 hours at one of FAA's designated testing centers.

FAA has free, online resources available. You can create a free online account on FAA's website, https://www.faasafety.gov/, and then register for online courses such as Part 107 Small Unmanned Aircraft Systems (sUAS) Initial:
https://www.faasafety.gov/gslac/ALC/CourseLanding.aspx?cID=451)

FAA has created a free study guide for Remote Pilot–sUAS; this is available on this website:
https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/media/remote_pilot_study_guide.pdf

The following sample questions for Unmanned Aircraft General (UAG) are appropriate study material for the Remote Pilot Certificate with a small UAS Rating. These questions are representative of questions that can be on the Unmanned Aircraft General tests but are not necessarily actual test questions
https://www.faa.gov/training_testing/testing/test_questions/media/uag_sample_exam.pdf

After you pass the exam, you will need to complete FAA Form 8710-13 for a remote pilot certificate. Additional information about how to get your license is available on this website:
https://www.faa.gov/uas/commercial_operators/become_a_drone_pilot/#ftp

The FAA test requires supplemental information (graphics, legends, and maps that are needed to successfully respond to certain test questions). This supplemental information is called FAA-CT-8080-2H, Airman Knowledge Testing Supplement for Sport Pilot, Recreational Pilot, Remote

Pilot, and Private Pilot and is available on this website:
https://www.faa.gov/training_testing/testing/supplements/media/sport_rec_private_akts.pdf

FAA LAANC
https://www.faa.gov/uas/programs_partnerships/uas_data_exchange/

North Carolina DOT UAS Operator Permit and Knowledge Test Study Guide
https://connect.ncdot.gov/resources/Aviation%20Resources%20Documents/UAS_Study_Guide.pdf

Florida Brochure of UAS Regulations and Guidelines
FDOT Aviation and Spaceports has developed an informational brochure for UAS. This brochure provides current regulations and guidelines to assist airports, UAS operators, the public, pilots, and law enforcements in increasing their knowledge of roles, responsibilities, and guidance related to UAS operations. It can be found on the FDOT UAS webpage:
https://www.fdot.gov/aviation/uas.shtm

Sample State DOT UAS Policy (Georgia DOT)
Georgia Department of Transportation has developed a policy for sUAS: Policy 3545-1. Policy and Operational Guidelines for Small Unmanned Aircraft Systems (Drones) (revised November 7, 2017). It can be found at the following link:
http://mydocs.dot.ga.gov/info/gdotpubs/Publications/3545-1.pdf

APPENDIX B. SUPPLEMENTAL ACCIDENT REPORTING INFORMATION (FAA and NTSB)

B.1 Accident Reporting–FAA

UAS accidents must be reported to the FAA. Information about Accident Reporting is included in Section 107.9 of Advisory Circular 107-2 (FAA, 2016). Below are some of the key points.

- Accident reports are required when there is a serious injury to a person, or when there is more than $500 in property damage (excluding any damage to the drone).
  - Definition of a serious injury is based on the Abbreviated Injury Scale (AIS), and includes injuries designated as level 3 (serious), 4 (severe), 5 (critical), or 6 (nonsurvivable injury). An example of a level 3 serious injury would be if someone requires hospitalization, but will fully recover, such as: head trauma, broken bone(s), or laceration(s) that require suturing.
  - The $500 in property damage reflects the lessor of either repair or replacement of property. If a UAV accident damages property with a fair market value of $200 and a repair cost of $600, no accident report would be needed.

- Accident reports for a sUAS flown under Part 107 must be made within 10 calendar-days of the operation that created the injury or damage, and may be submitted to the FAA Regional Operations Center (ROC) electronically (www.faa.gov/uas/), or by phone (817) 222-5006 for Indiana).
  - Reports may also be made to the Indianapolis Flight Standards District Office (FSDO). Contact information for the Indianapolis FSDO is as follows: phone 317-837-4400, fax 317-837-4423, 1201 Columbia Road, Suite 101, Plainfield IN 46168. Electronic documents can be sent to the assigned principal inspector or the general mail email, 7-AGL-IND-FSDO@FAA.GOV.
  - The report should include the following information:
    1. sUAS remote PIC's name and contact information;
    2. sUAS remote PIC's FAA airman certificate number;
    3. sUAS registration number issued to the aircraft, if required (FAA registration number);
    4. location of the accident;
    5. date of the accident;
    6. time of the accident;
    7. person(s) injured and extent of injury, if any or known;
    8. property damaged and extent of damage, if any or known; and
    9. description of what happened.

There are also cases (e.g., in the event of a fatality) in which a report must be filed with the National Transportation Safety Board (NTSB), as described below.

B.2 Accident Reporting–NTSB

Separate accident and incident reporting is required by the National Transportation Safety Board (NTSB) under 49 CFR §830.5, which is applicable for the operation of civil UAS (other than those operated for hobby or recreational purposes). To minimize reporting burden, it is not necessary to report a sUAS accident when there is only substantial damage to the aircraft and no injuries. Some of the key concepts are described below.

A civil UAS operator must immediately notify the NTSB of an accident or incident for an unmanned aircraft accident (defined in 49 C.F.R. § 830.2) in which any person suffers death, serious injury, or in which case there is "substantial damage" (unless damage is limited to the sUAS).

Serious incidents that apply to all UAS (regardless of weight) include (but are not limited to) the following events:

- Flight control system malfunction or failure: For an unmanned aircraft, a true "fly-away" would qualify. A lost link that behaves as expected does not qualify.
- Inability of any required flight crewmember (remote pilot or visual observer) to perform normal flight duties as a result of injury or illness; this does not include an optional payload operator.
- Inflight fire, which is expected to be generally associated with batteries.
- Aircraft collision in flight.
- More than $25,000 in damage to objects other than the aircraft.

Examples of potential events involving sUAS include the following:

- A small multirotor UAS has a fly-away and crashes into a tree, destroying the aircraft: Not an Accident, (though substantial damage, too small, and no injuries), but the operator is required to notify the NTSB of a flight control malfunction. NTSB may initiate an investigation and report with a determination of probable cause.
- A small multirotor UAS has a fly-away and strikes a bystander causing serious injury: Accident (resulted in serious injury). The operator is required to immediately notify the NTSB. The NTSB must investigate the accident and determine a probable cause.

Sources (Appendix B):

FAA. (2016, June 6). *Small unmanned aircraft systems (sUAS)* (Advisory Circular 107-2) [PDF File]. U.S. Department of Transportation Federal Aviation Administration. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_107-2.pdf

NTSB. (2016, July 29). *Advisory to operators of civil unmanned aircraft systems in the United States* [PDF File]. National Transportation Safety Board https://www.ntsb.gov/investigations/process/Documents/NTSB-Advisory-Drones.pdf

APPENDIX C. SUMMARY OF TOPICS ADDRESSED BY STATE sUAS POLICIES

Topic & Guidelines	FL	GA	LA	MN	NC	UT	WI	FAAA
I. Policy Statement Guidelines	X	X	X	X	X	X	X	X
1. Purpose	X	X		X	X	X	X	X
2. UAS Use	X		X	X		X	X	
A. Aerial Photography	X		X	X		X	X	
B. Photogrammetry	X			X		X	X	
C. Bridge Inspection	X			X		X		
D. Monitor Property & Structures	X			X		X		
E. Mapping Construction Sites	X		X	X		X	X	
F. Communications & Marketing	X			X				
3. 14 CFR Part 107	X	X	X	X	X	X	X	X
4. Certificate of Waiver/Authorization	X	X	X	X	X	X		X
5. Key Word Definitions				X		X	X	X
II. UAS Coordinator Guidelines		X			X	X		X
1. Coordinator Duties & Responsibilities		X			X	X		X
2. Department in Charge		X		X		X		
A. Duties and Responsibilities				X				
III. Equipment Guidelines		X		X	X	X		X
1. Purchase		X		X		X		
A. Criteria		X		X		X		
B. Forms		X						
2. Registration	X	X	X	X	X	X	X	X
A. FAA Rules & Regulations	X	X	X	X	X	X	X	X
B. State Requirements								
3. Maintenance/Inspection		X			X			X
A. Daily		X			X			X
i. Pre-Flight		X			X			X
i. Post-Flight					X			
B. Comprehensive		X						
C. Forms		X			X			
D. Appointed Personnel		X			X			X
IV. UAS Operator Guidelines	X	X	X	X	X	X		X
1. UAS Pilot	X	X	X	X	X	X		X
A. Roles & Responsibilities	X	X	X		X			X
B. Qualifications		X	X		X			X
C. Certification	X	X	X	X	X	X		X
i. Remote Pilot Certificate	X	X	X	X	X	X		X
ii. Knowledge Test	X		X		X			X
D. Training		X		X	X	X		X
2. Visual Observer(s)		X			X	X		X
A. Roles & Responsibilities		X			X	X		X
B. Qualifications		X			X			
C. Certification								

Topic & Guidelines (Continued)	FL	GA	LA	MN	NC	UT	WI	FAA
IV. UAS Operator Guidelines (Continued)	**X**	**X**	**X**	**X**	**X**	**X**		**X**
2. Visual Observer(s) (Continued)		**X**			**X**	**X**		**X**
D. Training		**X**			**X**			
3. Communication Standard		**X**			**X**			**X**
V. Operations	**X**	**X**	**X**	**X**	**X**	**X**		**X**
1. Operational Limitations	**X**	**X**	**X**	**X**	**X**	**X**		**X**
A. No Flight Over Persons/Traffic	**X**		**X**	**X**	**X**			**X**
B. Visual Line of Sight	**X**	X	**X**	**X**	**X**			**X**
C. Flight During Daylight	**X**	**X**	**X**	**X**	**X**			**X**
D. Class G Airspace Only	**X**	**X**		**X**	**X**			**X**
E. State Regulations	**X**							
F. Fly Under 400 Feet	**X**	X	X	X	X			X
G. Fly at or Under 100 MPH	**X**		**X**		**X**	X		**X**
2. Pre-Flight Operations		X			**X**	**X**		**X**
A. Planning		**X**			**X**			**X**
B. Inspection		**X**			**X**			**X**
C. Weather	**X**	**X**			**X**			**X**
D. Pre-Flight Checklist		**X**			**X**			
E. Documentation		**X**			**X**			
3. During Flight Operations		**X**			**X**			
4. Post-Flight Operations		**X**			**X**			
A. Post-Flight Checklist		**X**			**X**			
B. Documentation		**X**			**X**			
5. Emergency Procedures					**X**			X
A. Loss of Datalink					**X**			
B. Loss of GPS					**X**			
C. Autopilot Software Error/Failure					**X**			
D. Loss of Engine Power					**X**			
E. Ground Control System Failure					**X**			
F. Other Aircraft Intrusion					**X**			
VI. Flight Area Management	**X**	X	X	X	**X**			X
1. Launch Site		**X**			**X**			
2. Landing Site					**X**			
A. Alternate Landing Site					**X**			
B. Mission Abort Site		X			**X**			
3. Airspace	**X**	**X**	X	X	**X**			X
A. Rules & Regulations		**X**			**X**			**X**
B. Restricted Airspace	X	**X**	X	X	**X**			**X**
i. Authorization	**X**	**X**			**X**			**X**
VII. Accident Reporting		**X**			**X**			**X**
1. Accident Defined		**X**			**X**			**X**
2. Documentation		**X**			**X**			**X**
VIII. Insurance Coverage					**X**			
IX. Privacy		**X**		**X**		**X**		

Source (Appendix C):

Bausman, D., Burgett, J., Chowdhury, M., Greider, P., & Brunk, K. (2019). *UAS policy at state departments of transportation* (Paper No. 19-01748). Transportation Research Board Annual Meeting.

APPENDIX D. GLOSSARY OF TERMS AND ACRONYMS

ASCE	American Society of Civil Engineers	LiPo	Lithium Polymer
ATC	Air Traffic Control	LOA	Letter of Agreement
ATO	Air Traffic Organization	MDOT	Michigan Department of Transportation
CFI	Certified Flight Instructor	MnDOT	Minnesota Department of Transportation
CFR	Code of Federal Regulations	MFT	Maximum Flight Time
COA	Certificate of Authorization or Waiver	MOT	Maintenance of Traffic
CONOPS	Concept of Operations	MUAV	Micro Unmanned Aerial Vehicle
CV	Columbia Village	NAS	National Airspace
DOT	Department of Transportation	NDT	Non-Destructive Testing
EDC	Every Day Counts	NPRM	Notice of Proposed Rulemaking
EOC	Emergency Operations Center	PIC	Pilot in Command
ESC	Electronic Speed Controller	RC	Radio Control
FAA	Federal Aviation Administration	SAC	Special Airworthiness Certificate
FAR	Federal Aviation Regulations	SGI	Special Government Interest
FDMS	Federal Docket Management System	SJ	Slip Joints
FDOT	Florida Department of transportation	sUAS	Small Unmanned Aerial System
FHWA	Federal Highway Administration	sUAV	Small Unmanned Aerial Vehicle
FPV	First Person View	TDGT	Total Data Gathering Time
FSDO	Flight Standards District Office	TSA	Transportation Security Administration
GDOT	Georgia Department of Transportation	UAS	Unmanned Aerial System
HD	High Definition	UAV	Unmanned Aerial Vehicle
HML	High Mast Luminaire	UBIU	Under Bridge Inspection Unit (aka snooper truck)
HMLP	High Mast Lighting Poles	VLOS	Visual Line-of-Sight
IFR	Instrument Flight Rules	VMC	Visual Meteorological Conditions
INDOT	Indiana Department of Transportation	VO	Visual Observer
IR	Infrared	VTOL	or VTAL Vertical Take-Off and Landing
LiDAR	Light Detection And Ranging	WSDOT	Washington State Department of Transportation

APPENDIX E. PUBLIC INFORMATION FROM DOTs REGARDING EMERGENCY RESPONSE, BRIDGE INSPECTION AND CONTRACTOR PROVISIONS (e.g., FOR CONSTRUCTION)

State	Information Displayed As	Date	Emergency Response	Contractor Provisions	Bridge Inspection	Comments
Alabama	Standard operating procedures	5/15/2017	N/A	Must have all safety forms and follow ALDOT procedures Must attend safety classes at least once annually.	Authorized mission however PIC must attend Advanced operator course for that system and mission.	Must get permission before using drones for ALDOT mission.
Alaska	Facts and guidelines	October 1, 2015	N/A	N/A	N/A	Mostly deals with privacy issues and FAA Regs. Government use not mentioned.
Pennsylvania	Policy	April 2019	N/A	Must follow PennDOT employee UAS policy Must have insurance.	Recognizes potential.	Mission assistant and visual observer.
Texas	Manual	4/2017	N/A	May be contacted for the recovery of downed aircraft.	Did Not specifically mention bridge inspections but does mention flying near bridges.	Two fold approval for missions. Flight plan submission required Requires contacting TXDOT for recovery of downed aircraft in any location reasonably expected to endanger a person or persons (such as trees or utility lines). Focused on emergency downed

State	Information Displayed As	Date	Emergency Response	Contractor Provisions	Bridge Inspection	Comments
						aircraft response.
North Carolina	Collection of laws and regulations.	N/A	N/A	N/A	N/A	Must pass a knowledge test and obtain a permit.
Washington	Policy	N/A	Exceptions to stating a purpose of use in advance of actual use.	N/A	N/A	Mainly focused on law enforcement.
Georgia	Policy	11/07/2017	N/A	UAS Program manager oversees any contractor project on behalf of GDOT.	N/A	Standard “Basic Principle.”
Florida	Overview of regulations and laws	2019	N/A	N/A	N/A	Aimed toward Denying UAS interference of critical structures and FAA Regulations.
Louisiana	Neither	N/A	N/A	N/A	N/A	Collection of rules. Required to follow FAA regulations and avoid invasion of privacy.

State	Information Displayed As	Date	Emergency Response	Contractor Provisions	Bridge Inspection	Comments
Minnesota	Policy	June 18, 2015 Revised July 29th, 2016 Revised again March 16th, 2018	N/A	Must follow MnDOT employee policy and FAA regs.	Example of a mission i a bridge inspection	Will not authorize UAS for MnDOT projects by persons unaffiliated with MnDOT. However, notes that FAA Regulations generally do not require MnDOT Authorization. May have special circumstances in which MnDOT authorization will be required, must contact the Office of Aeronautics.
Ohio	policy	12/18/2017	N/A	Third parties required to follow FAA regulations.	N/A	Ohio/Indiana UAS Center located under the ODOT established to advance UAS commercialization in the region, and support flight operations for Government Agencies.
Wisconsin	Information Page	N/A	N/A	N/A	N/A	General overview of FAA Regulations and definitions.
Utah	Policy	March 22, 2017	Aspects of policy do not restrict safe rapid deployment of emergency UAS.	Contractors for UAS service require approval of the deputy director or designee Must follow UDOT employee policy.	Permitted use	Must provide cost efficiency, improved data quality, or improved safety over existing method. Employees prohibited from using privately owned UAS for department business. Must avoid capturing images of the public, except those incidental to the project.

Sources (Appendix E):

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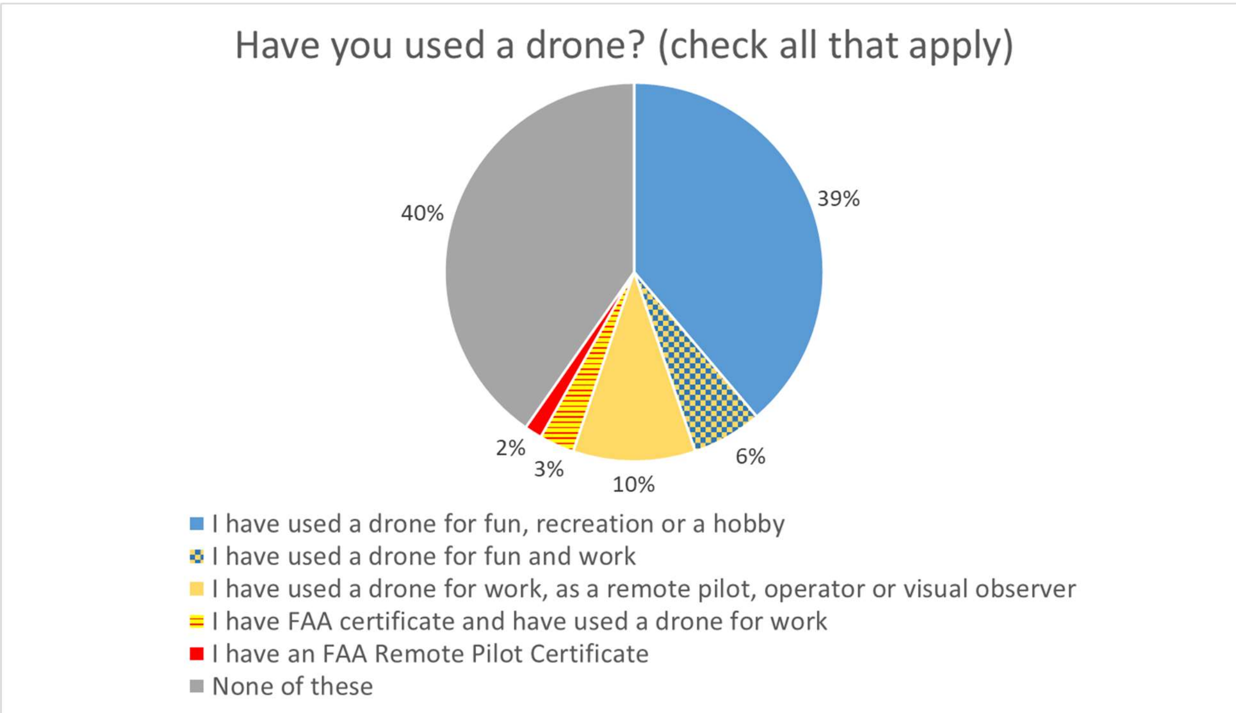
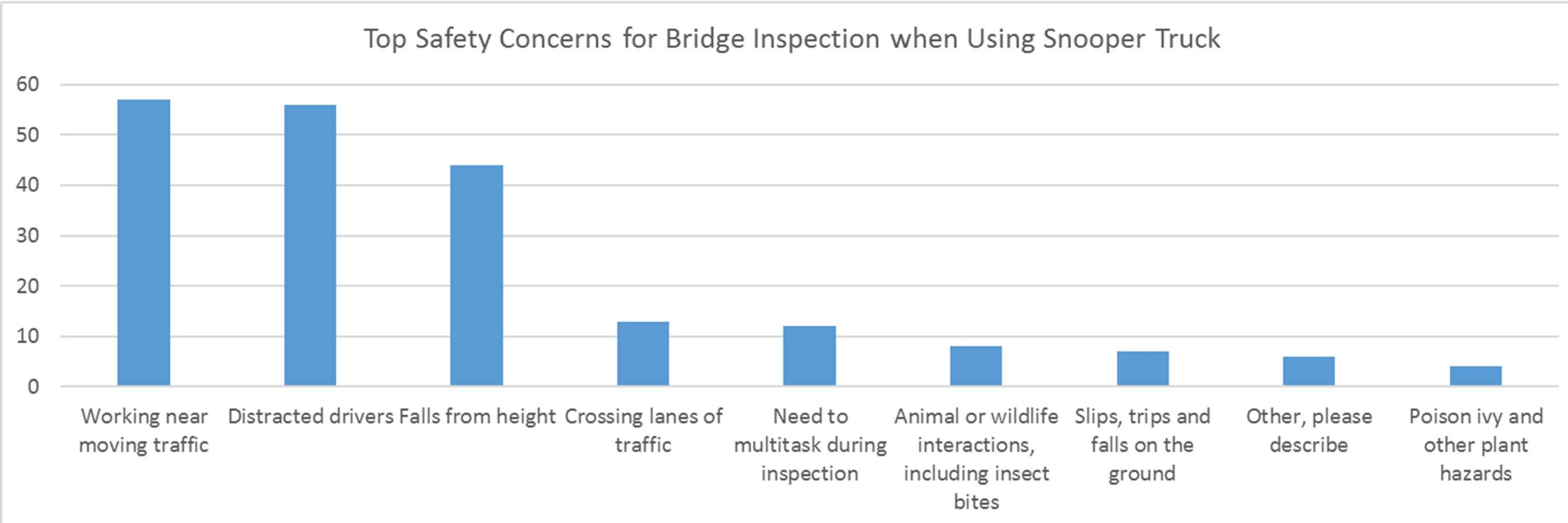
APPENDIX F. SUMMARY OF FINDINGS FROM SURVEY OF BRIDGE INSPECTORS

Compiled September 6, 2019, based on 65 responses, although not all respondents answered every question. Responses have not been edited.





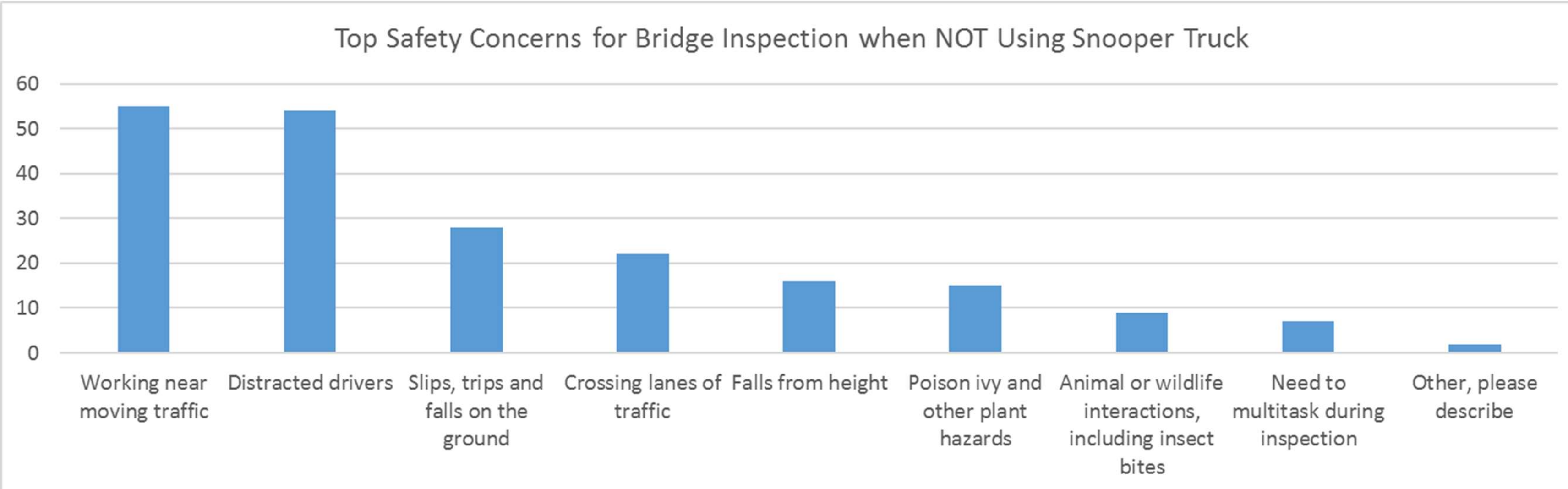
Note: Other: Obtaining competent traffic control.

Hitting head on underside of bridge.

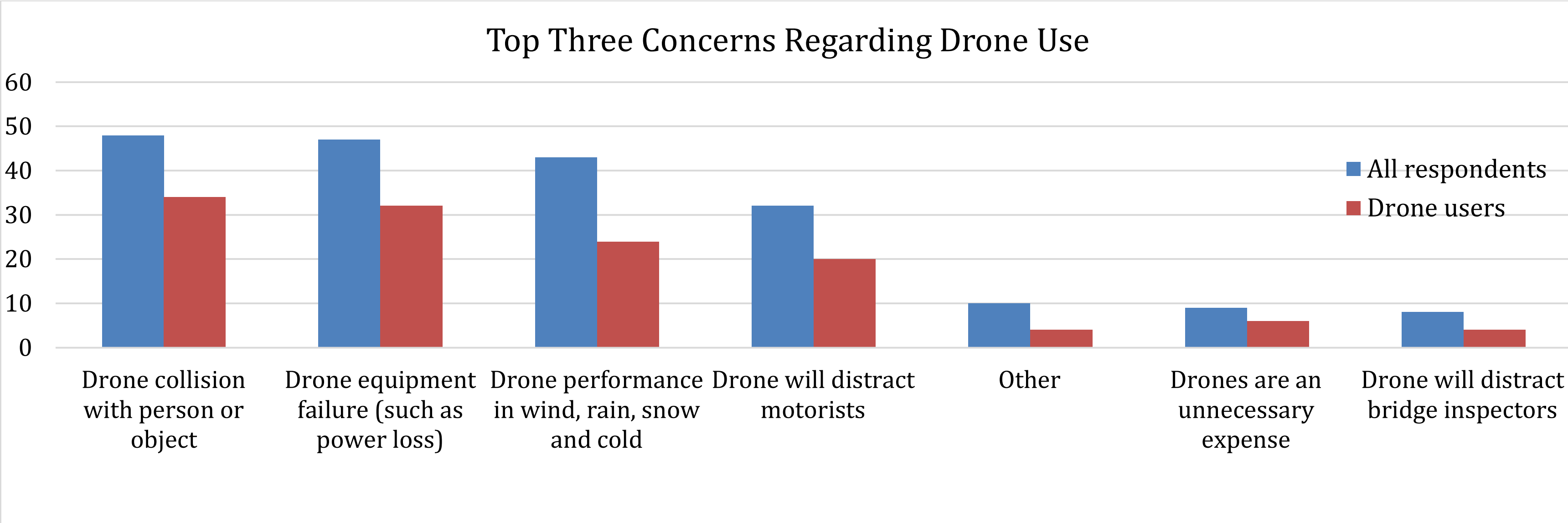
If the hydraulics have been inspected recently, is the truck operator skilled?

Using the machine to its limits.

Bridge debris falling to areas below.

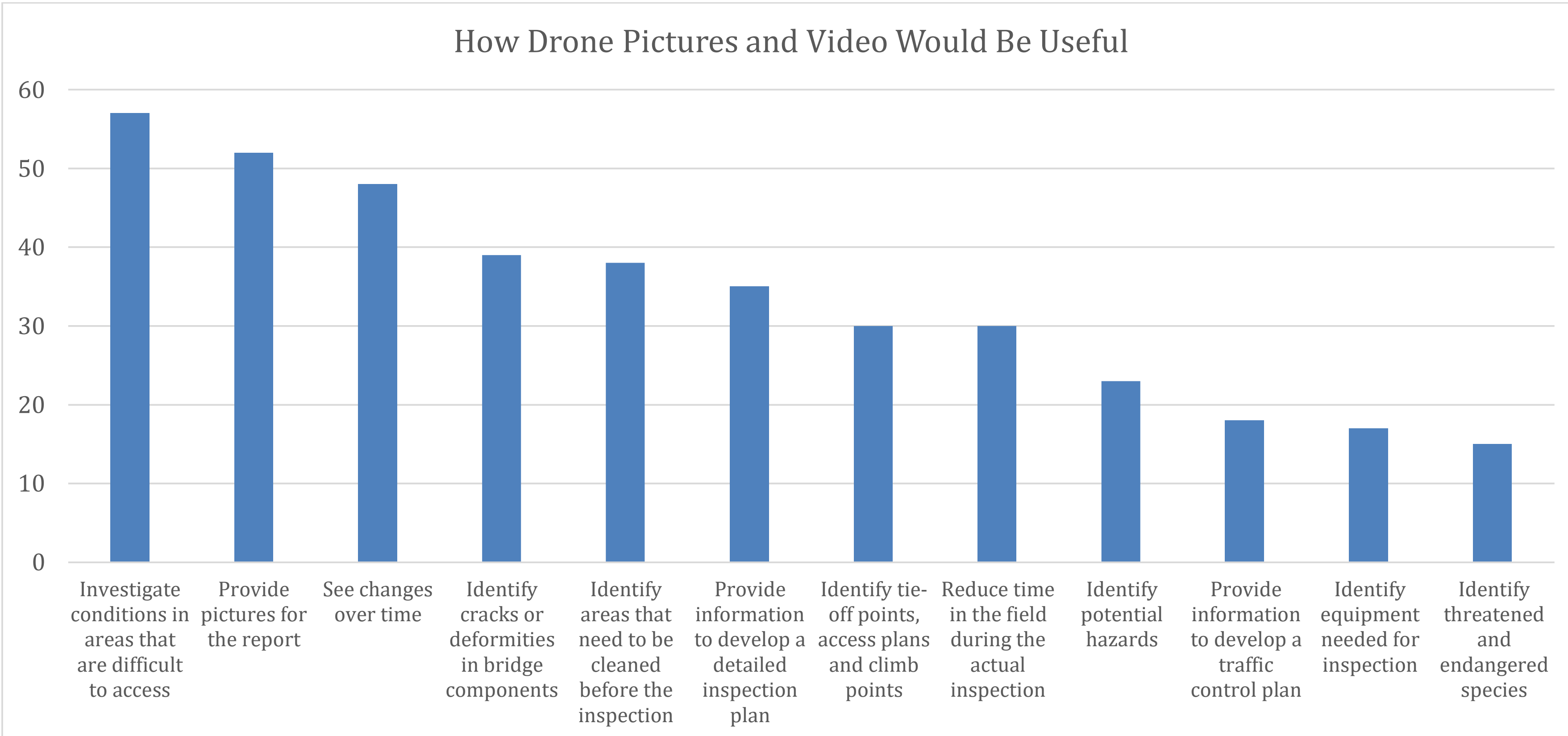


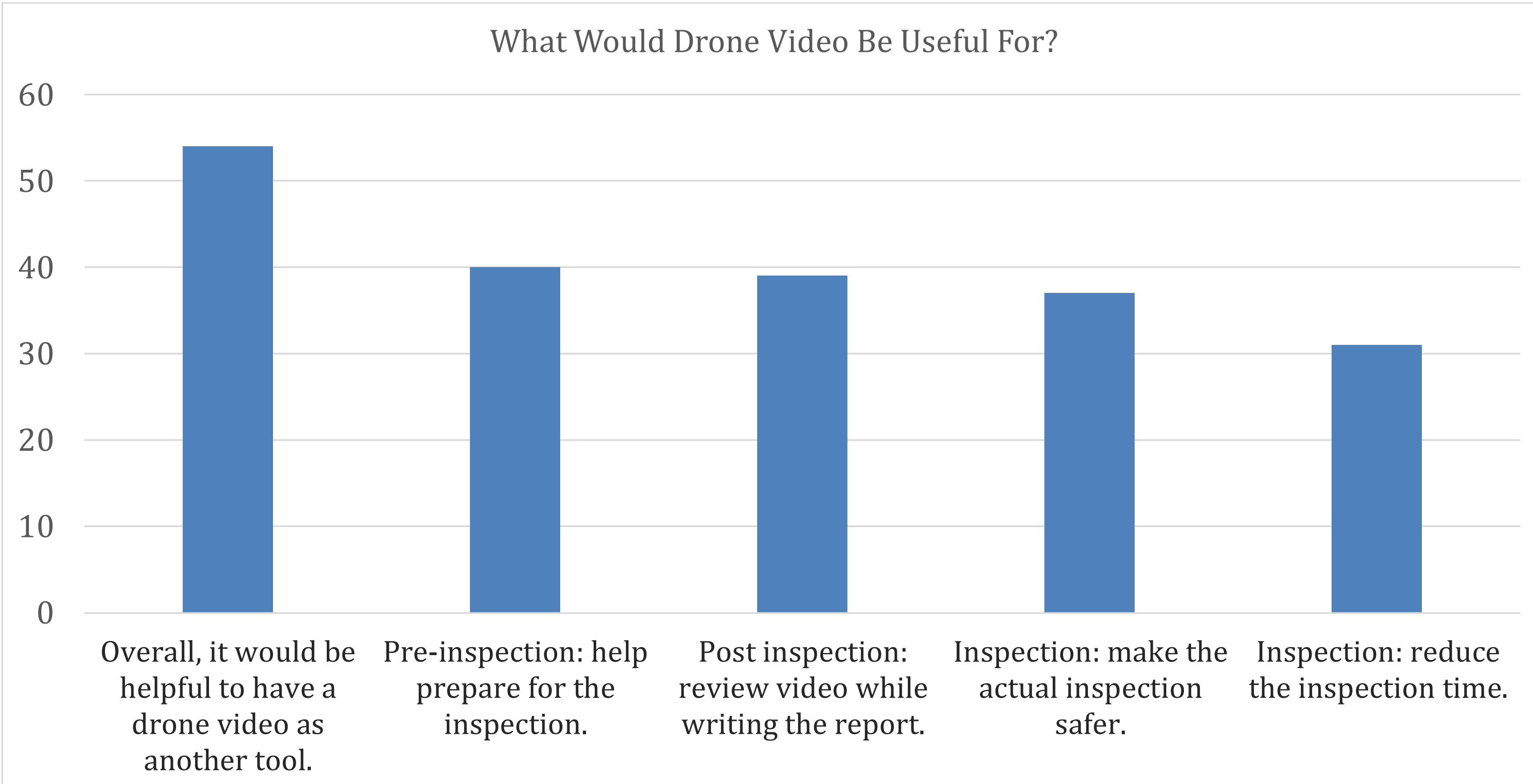
Note: Other: Homeless/people living under the bridges.
Safety hazards to public from bridge.



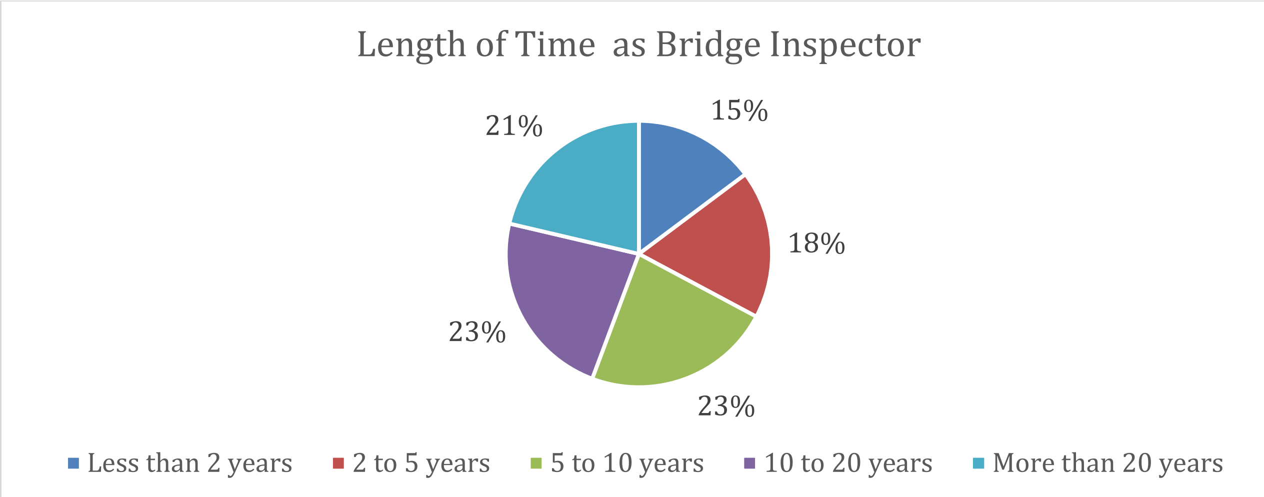
Other:

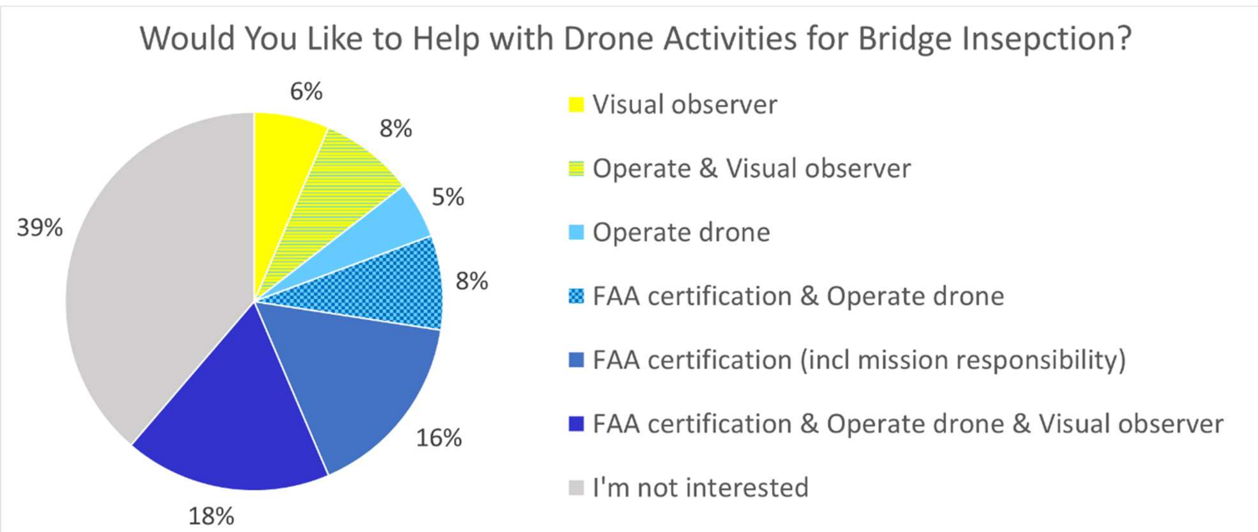
Concerns regarding drone use	**Experience with drones (question 1)**
No concerns! Totally worth it.	Have used drone for fun and work.
Useful for general inspection only, have strong reservations regarding fracture critical inspections/complex inspections.	Have used drone for fun.
Not being able to adequately see and feel the area being inspected. In person is always better than a photograph.	
They should be used for safety and cost savings.	
FAA clearance.	Have not used drone.
Time for planning and post analysis.	
Increased time for inspection.	
Drone Equipment communication with Bias and Bently Systems.	
Inspecting via video screen vs. Inspector eyes.	
close look up and details.	


How Drone Pictures and Video Would Be Useful
60
50
40
30
20
10
0
Investigate conditions in areas that are difficult to access
Provide pictures for the report
See changes over time
Identify cracks or deformities in bridge components
Identify areas that need to be cleaned before the inspection
Provide information to develop a detailed inspection plan
Identify tie-off points, access plans and climb points
Reduce time in the field during the actual inspection
Identify potential hazards
Provide information to develop a traffic control plan
Identify equipment needed for inspection
Identify threatened and endangered species



Note: 83% of respondents selected the response, “Overall, it would be helpful to have a drone video as another tool for bridge inspection.”





Would you like to help with drone activities for bridge inspections?

	How long have you been a bridge inspector?					
	< 2 years	2 to 5 years	5 to 10 years	10 to 20 years	> 20 years	**Total**
I would like to operate the drone (no FAA certification required).	0	7	5	6	6	24
I would like to be a visual observer.	1	7	4	4	4	20
I would like to be responsible for drone missions as a remote pilot with FAA certification.	0	8	5	8	3	24
I'm not interested in doing any of these.	6	2	6	3	6	23
Total	**7**	**11**	**14**	**14**	**13**	**59**

What do you like about the current bridge inspection software?
If speaking of BIAS, we have an issue with exporting Bridge History information. I haven't had many other problems but don't use it daily.
It is intuitive and easy to create reports.
it is OK.
Consistency.
concise, has basics of what is needed.
Easy to use.
I like that it allows direct entry of submittal to INDOT.
It streamlines the inspection process.
BIAS puts everything in one place. It is a good concept but still needs improving.
Easy to use.
Compiled data.
I like that all the bridge inspection information is tied into one place.
All data in one place.
Uniform presentation of asset history and findings.
?
Familiar with it but could be better.
Not much.
Ability to see a large or little selection of a single bridge's report.
Easy to use.
user friendly.
It is simple to operate.
All data in one location.
Easy to use.
I like the BIAS software. It is much better than the old paper based method.
Not familiar with software.
Need better product.
Availability of data.
It produces a report when complete.
I have not used the software enough to be able to give a proper answer.
to many glitches.
Easy to use.
BIAS: The increased connectivity with ERMS and other INDOT databases to allow quicker data searches.
Able to use in the field and consistency.
Ease of use.
Ease of use.
It is good when it functions properly.
It holds data.

What are limitations of the current bridge inspection software?
Would be nice to have a trend line of component condition ratings to see how a rating has changed from year to year.
It takes time to upload reports from outside sources.
Data verification.
Can't create truncated report like previous software.
Hard to expand for more detailed inspection needs.
Not fast enough.
I would like to see ability to add photos with voice annotations.
It isn't easily customized and is too reliant on 3rd parties for development.
Too many locations to upload information, i.e., BIAS, BRADIN, ERMS. Front end tables often have problems. Software has many glitches that often need the user to know about and how to avoid them.
Timely repairs.
Cumbersome interface.
There are quite a few features that have glitches or do not work properly. Ex: county summary reports, limitations with scour channel measurement creator.
Frequent low running times/unresponsiveness.
Incomplete bridge records.
Mapping is limited and not user friendly, searching for structures is not easy.
Unable to merge reports on the Ipad.
Wifi
Have a window open that shows a list of the bridge report items that will stay open as you create a query.
Down time for errors or changes.
NA
Queries
There is no way to tag a framing plan of the structure with relevant photographs and detailed descriptions of defects, which would allow inspectors to look at the same spot reliably inspection over inspection.
BMS and forecasting.
I would like to have a 3D model based inspection.
Not familiar with software.
Reliability.
Speech to text would be helpful. Formatting in app is bad.
Loading # of bridges.
Currently the software seems buggy.

What are limitations of the current bridge inspection software? (continued)
Not very user friendly.
data different places, misc, paint, etc.
1: Connection and processing speed of the servers the data is stored on. 2: Multiple errors in data entry of old data into ERMS.
Really putting a lot of verbiage to correctly depict deficiencies.
Unreliable
Collector App does not always function properly. Poor support from the manufacture causing errors in the program.
Not enough time or space for this one...

Please feel free to share any other thoughts you have about using drones for bridge inspection safety.
Should not take the place of fracture critical inspections but could be used to supplement inspections where access is difficult.
Snoopers are very expensive and only truly needed for a portion of the bridges they are used on.
Recently used very expensive drone piloted by City of Fort Wayne personnel for inspection in Allen County. Needed arms' length inspection on prestressed concrete beams looking for hairline cracks near ends (2/3 of beams had them). Drone took great pictures & videos. However, it was very difficult to distinguish in the field between a possible crack and a spider web. Overall, I think for Routine inspections drones are a fantastic idea, especially on long multi-span bridges over water or trains where access is difficult. However, for detailed, fracture-critical type inspections, hands-on is still the way to go.
We have used a few high end drones for bridge inspection including the Intel Falcon 8 which is incredible stable in high winds and has the ability to look up. We have found that this equipment is currently cost prohibitive for a consultant to purchase (although rental is manageable) and the lower cost drones do not effectively handle winds and do not "look up"—which is critical for any bridge inspection drone.
I think using drones would give you the opportunity to perform a preliminary inspection while staying at a distance from traffic and other hazards. It would also be useful during construction, flooding, or other natural disasters when access is limited. Arial photos of bridges and their streams would be helpful for monitoring channel migrations.
many of the items listed as possible uses for a drone can be completed from the office while looking at existing plans and a site visit to see the bridge from the ground. Most usage would be limited to larger bridges. Do not believe that you can see defects as well from a drone as you could with the naked eye. They could have a use in damage inspections where there are concerns about the safety of the bridge to keep the inspector's off of a bridge that might have major damage, such as fractured member.
I have conducted multiple bridge inspections as a FAA licensed Part 107 pilot and SPRAT level 3 inspector. UAS incorporation has reduced man-at-risk hours by nearly 50-80% depending on structure type where traditional rope access would be applied. This is especially applicable for cable-supported structures.
It's a tool. Just like a hammer. It has benefits to bridge inspections. Once costs (equipment and training) are reduced, it would be great to see every inspection team have one in their inspection tool box.
I believe a skillful well trained drone pilot would be able to safely complete a bridge inspection using a drone.
Overall a cost effective and time saving tool. Also, drones would be great addition for inspecting large culverts that cannot be entered due to size restrictions. They would also provide an aerial photo; this would be useful to the asset engineer's and surveyor's for exact location. There have been times when the wrong asset was replaced. GPS/ GIS is not reliable in some areas and RP's are off.

Please feel free to share any other thoughts you have about using drones for bridge inspection safety (continued).

You would be able to inspect piers without the need of a ladder or boat.

Battery life issues; taking stills while recording video is a plus.

A drone is a potential added value tool large bridges. There is not much value to add to the typical county bridge inspection as the assets, equipment, and time necessary to implement a drone to every county bridge is not cost effective. The equipment limitations of having a drone with a battery life lasting 15 minutes requires the use of half dozen batteries and constant charging to keep it in use for a 12 hour work day for field activities. From my drone experience, the models I've used have limited up angle for the camera and the bridges are surrounded by trees thus making it a risky venture to deploy the drone to get close enough to take detailed photos sufficient for inspection.

Our firm has a certified drone pilot and we have been using them to supplement our inspection activities, although they cannot replace the hands on inspections, they are very useful and the video is great for reviewing while finishing reports, doing load ratings, etc. in the office. We are fully invested in using drone technology to our advantage in the NBIS field. The biggest thing I see is that it can reduce risk to our inspectors, instead of climbing ladders, snoopers, etc., drones can get as close as an inspector and take great pictures and videos. Any issues can then be pinpointed for hands on inspection, limiting risk time.

I feel that widespread implementation of drones for bridge inspection are an unnecessary taxpayer expense and worry that reliance on widespread use of drones will increase the average time for bridge inspections (field and office components). At this time, I feel that drones should only be considered for use in specialized cases.

Drones have a potential to a useful tool for bridge inspection. They could provide an option that would help identify areas that need a closer look by inspectors and areas that need to be addressed by maintenance.

We've used drones before to inspect locations that are difficult to access. It seems like they could be helpful in that way, but I think you still have to have eyes on the drone in order to fly to the location you're inspecting. Also, as I understand, any business related drone activities do require an FAA permit.

I feel that drones are going to be an essential tool used for inspection and construction. This is a field we as inspectors should really start looking into.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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